X-ray binaries I

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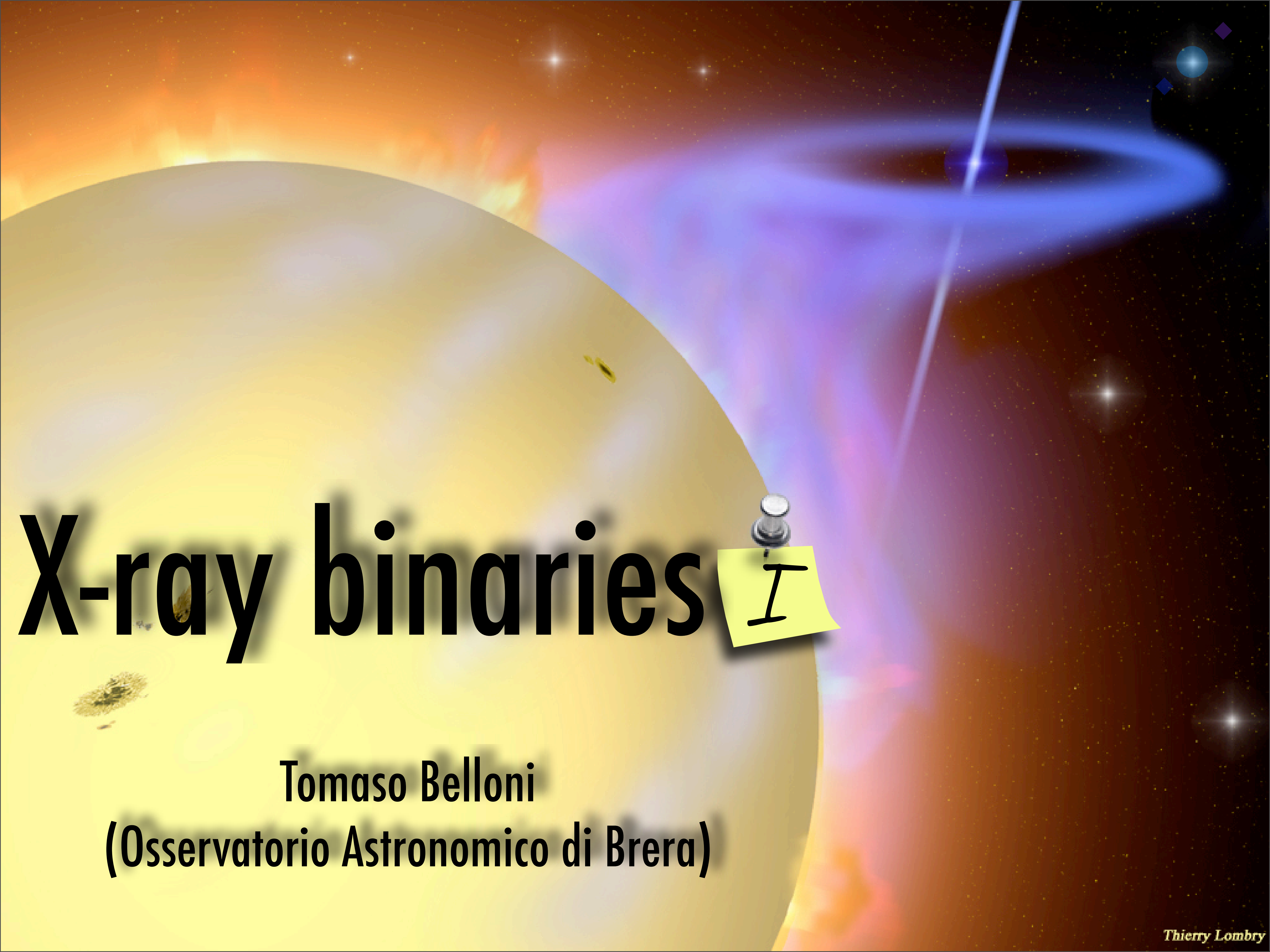

Thierry Lombry

- Part I
  - X-ray pulsars
  - Neutron star LMXB
- Part II
  - Neutron star LMXB
  - Black-hole binaries

NS, B field

small R, GR

X-ray pulsars

DISCOVERY OF PERIODIC X-RAY PULSATIONS IN CENTAURUS X-3 FROM *UHURU*

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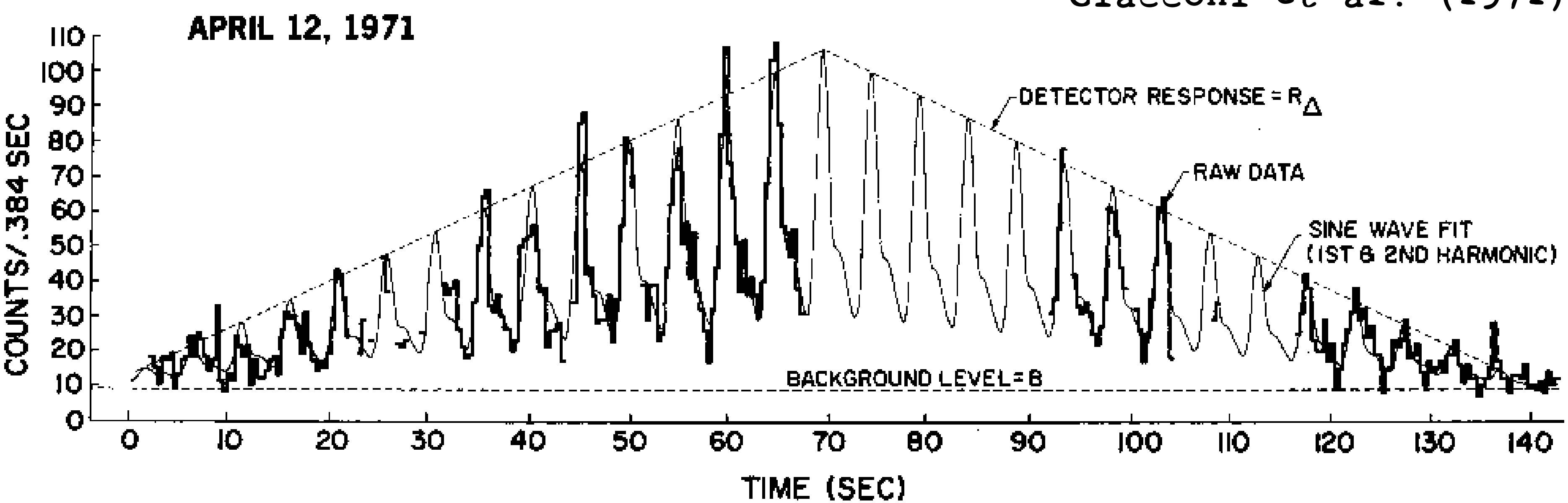
DATA ON X-RAY PULSARS

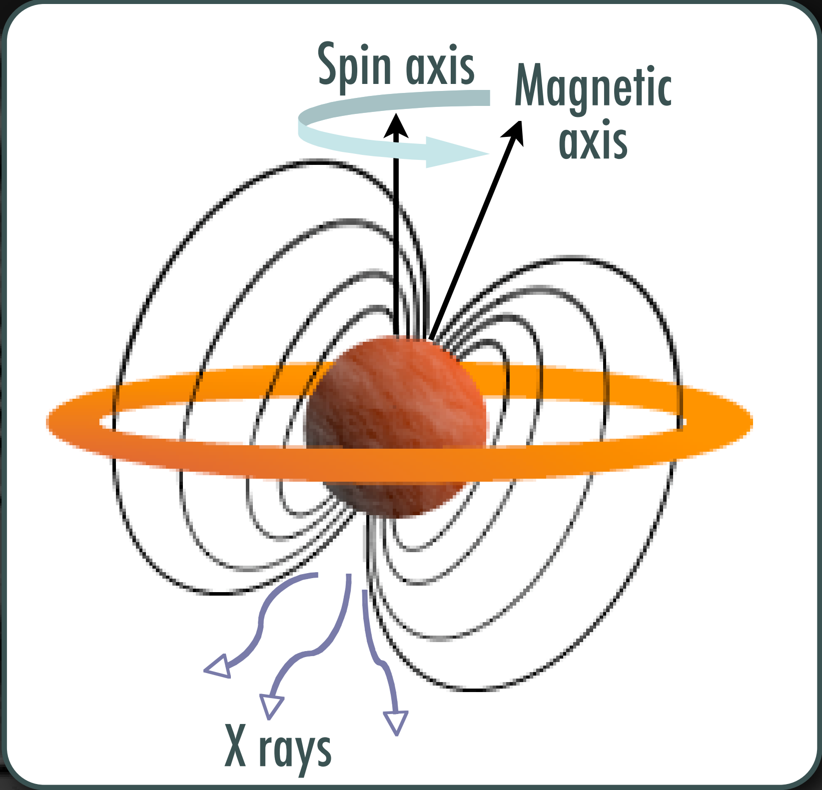
PARAMETER	STAR: NP 0532*	STAR: Cygnus X-1†	STAR: Centaurus X-3
Period τ (seconds)......	0.033	0.073 or 0.292 1.1 or 1.3 Possibly >5	4.87

Giacconi et al. (1971)



Magnetized NS accreting from a non-collapsed star

A fraction of the X rays are modulated at the spin period



$B=10^{12}$-10^{13} G

Accretion mechanisms depend on the properties of the donor

About 100 in HMXB

90 in transient Be/X systems

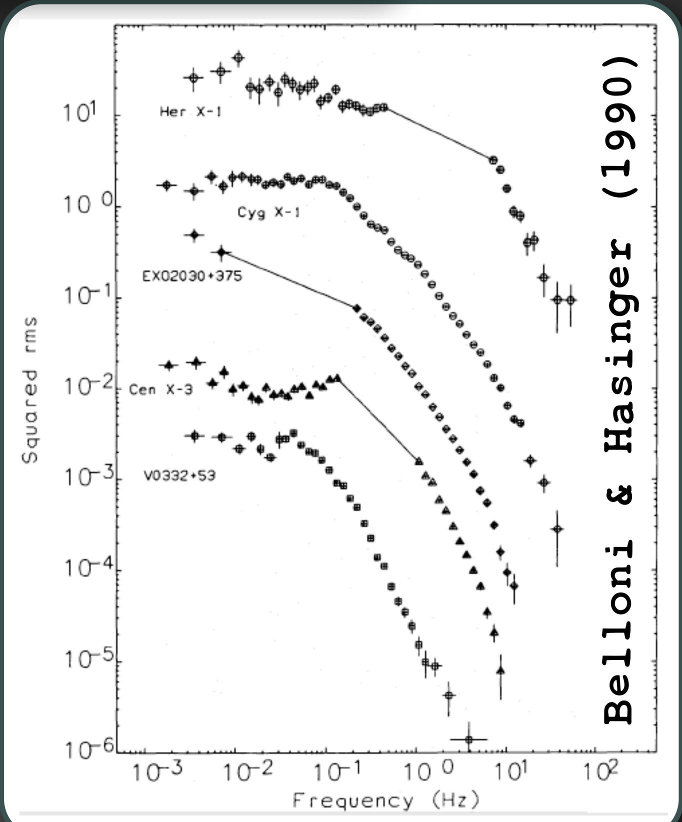
15 in persistent systems

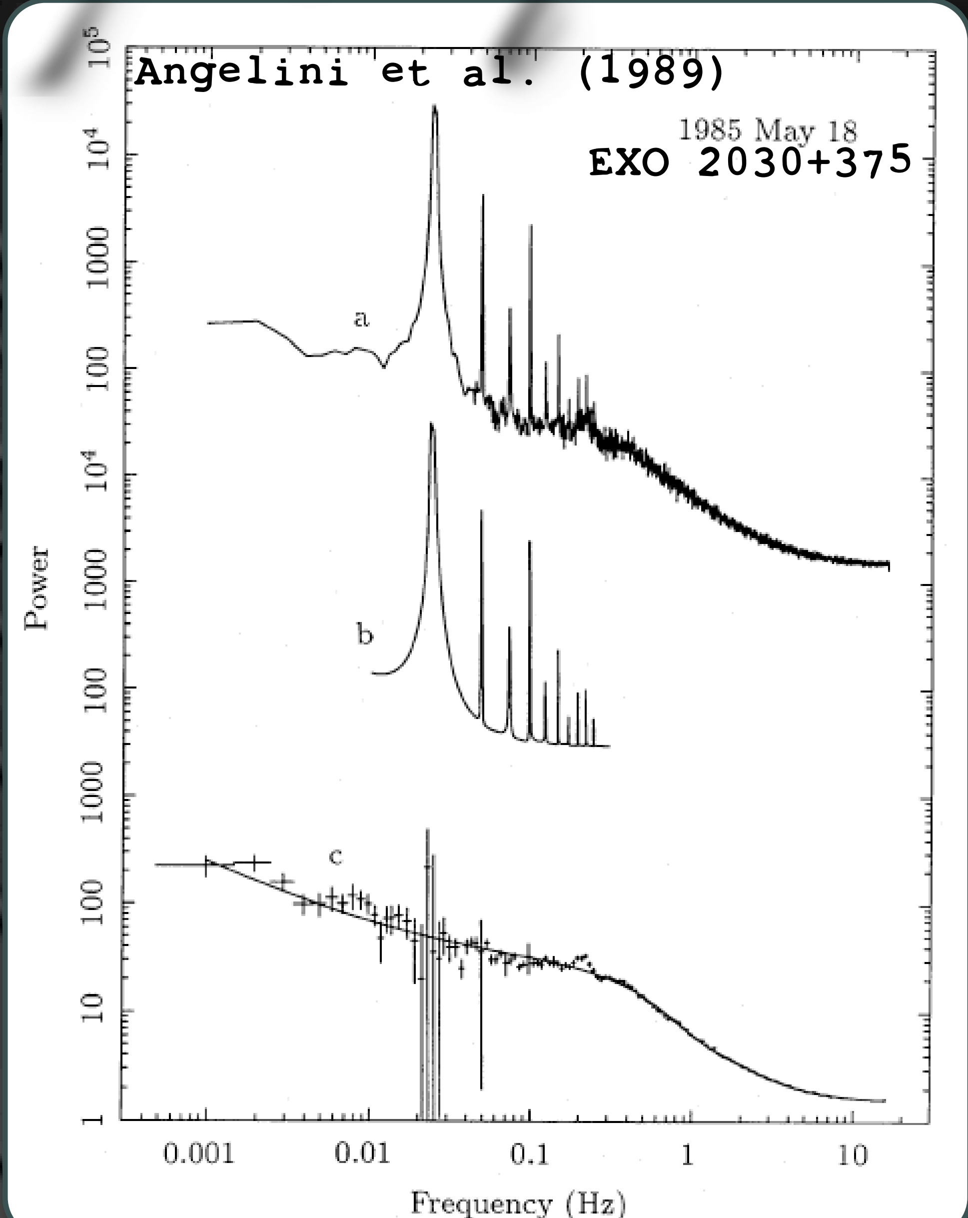
a dozen in LMXB

no common characteristics

Pulse periods from 69 ms to 3 hr

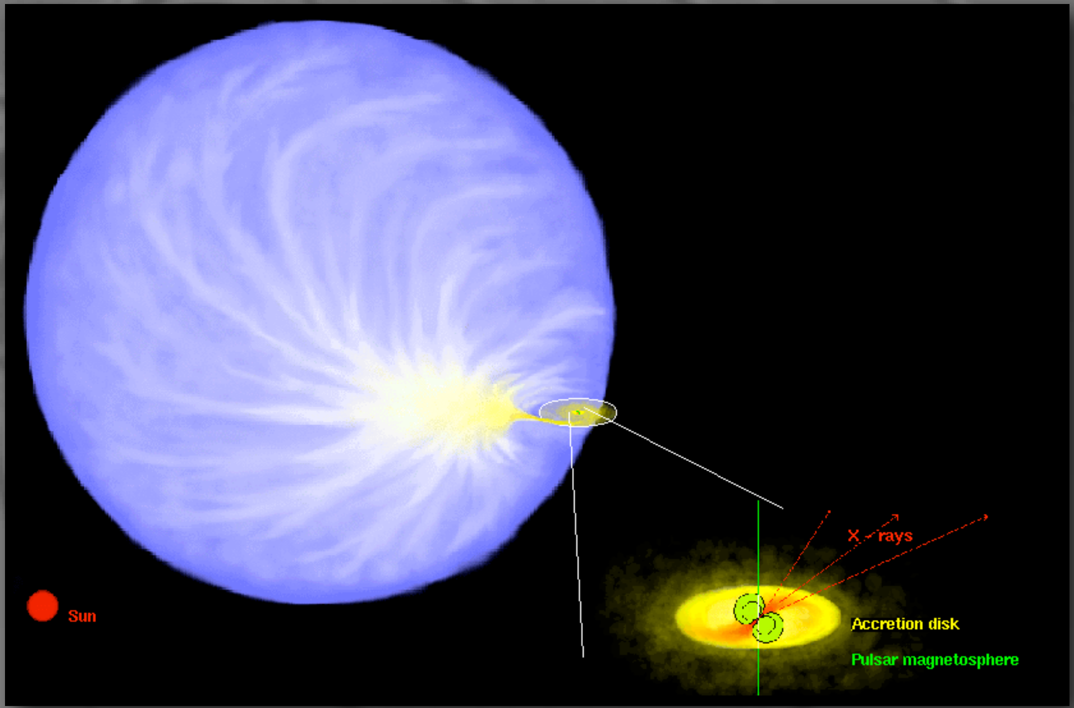
Periodic signal
Broad-band noise
QPO peaks





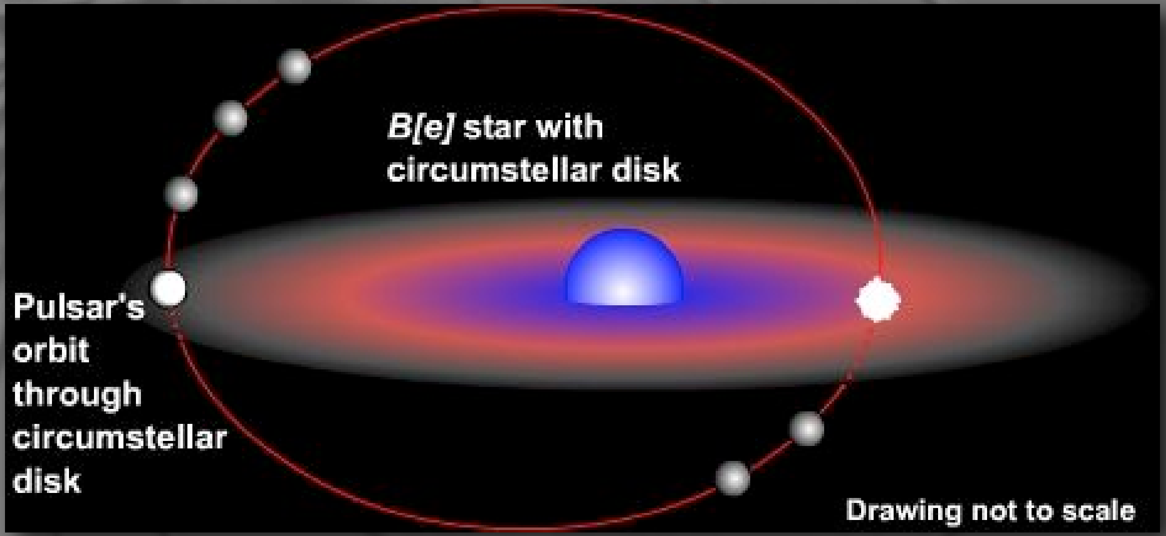
HMXB: young NS accreting from early spectral type giant or supergiant stars (O or B). The companion stars may eject as much as 10^{-5} M yr $^{-1}$ of their mass in the form of stellar wind (wind-driven systems), or may fill their Roche lobe.

- High B (10^{12}-10^{14} G)
- Spherical/RL mass loss geometry
- Low specific angolar momentum J/M
- Small accretion disk (if any)
- Relatively close (P_{orb} = days)
- Persistent X-ray flux
- L_X in the 10^{35}-10^{37} erg/s range



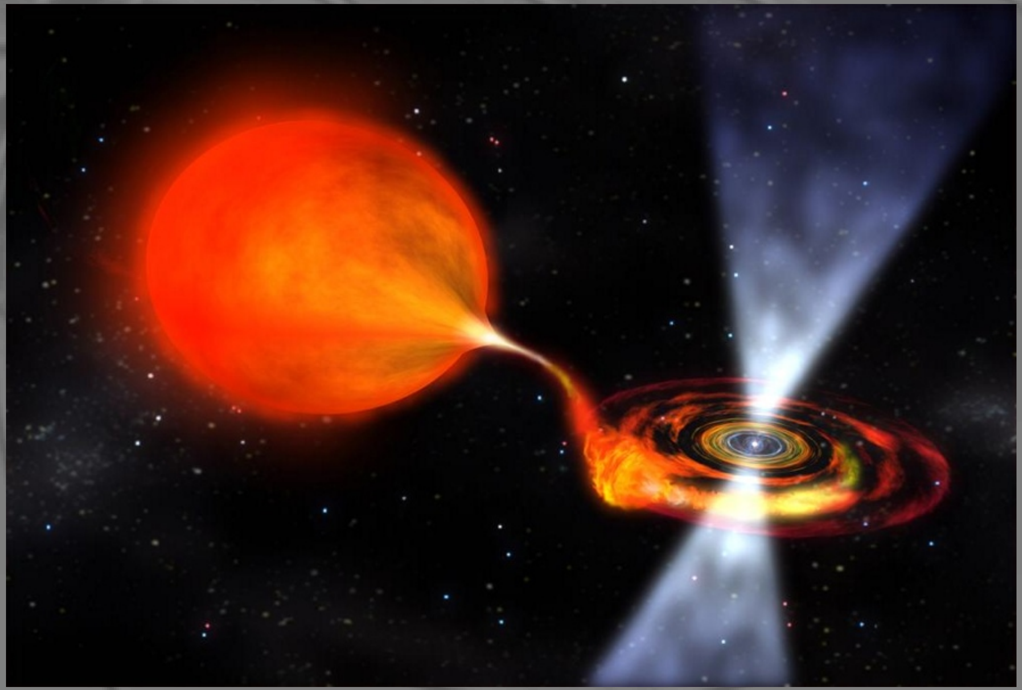
BeXB: young NS accreting from a rapidly spinning (0.7 break-up) Be stars in highly eccentric (e>0.3) binary systems due to equatorial mass-loss episodes

- High B
- Anisotropic mass loss
- High specific angolar momentum
- Relatively large accretion disk
- Large systems (P_{orb} = months)
- Transient X-ray flux
- L_X from 10^{38} downwards
- Majority of systems



LMXB: old/young NS accreting from late-type stars (K or M). The companion fills its Roche lobe or loses matter through L_1 (disk driven system)

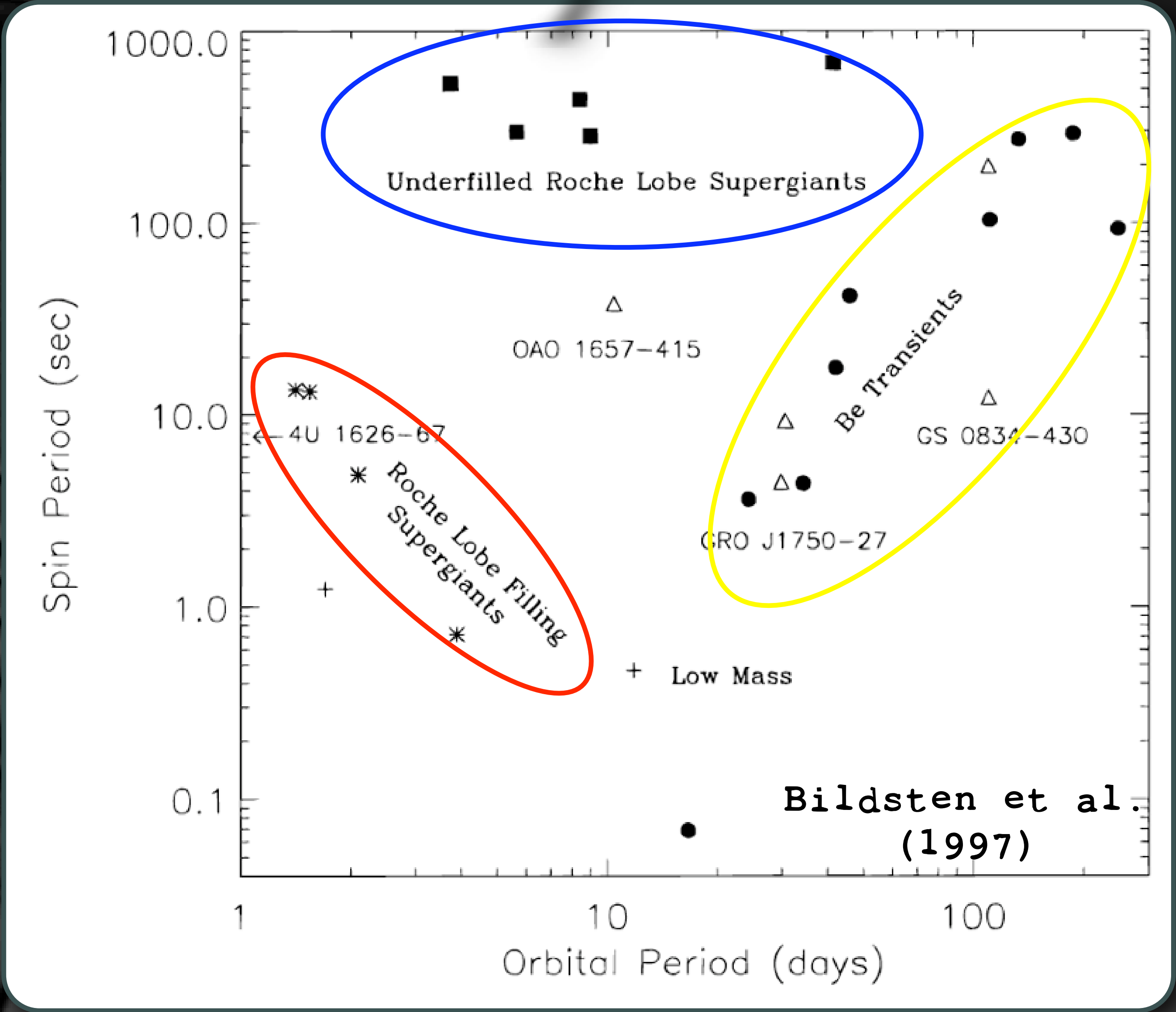
- B can be as low as (10^8-10^9 G)
- Anisotropic mass loss
- High specific angolar momentum
- Large accretion disk
- Close systems (P_{orb} = hours)
- Transient or persistent X-ray flux
- L_X from a few 10^{38} downwards
- Few objects



The "Corbet" diagram

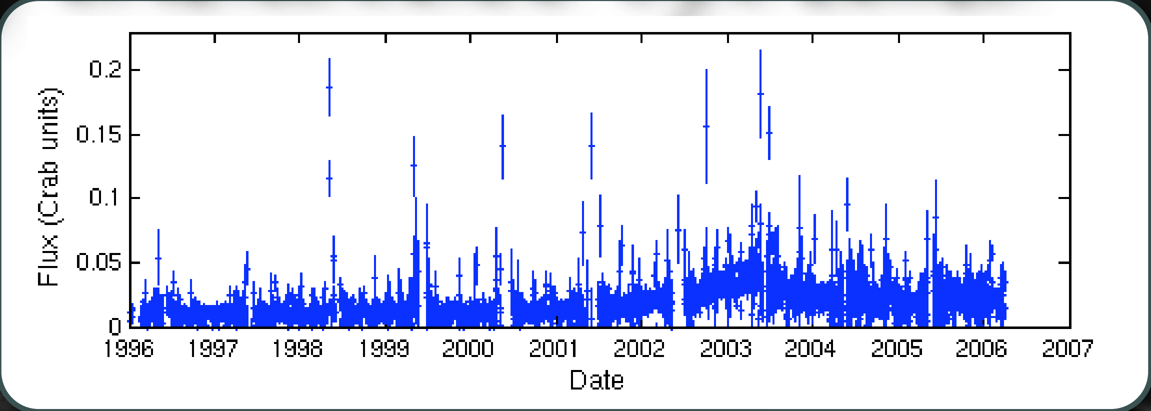
- RL SG: short P_{spin}, short P_{orb}, L_X>=10^{37} erg/s anti-correlation?
- WF SG: long P_{orb} (obvious), L_X=$10^{35\text{-}37}$ erg/s
- Be T: correlation

- Long period
- Large distance
- Lower accretion rate
- Longer equilibrium P_{spin}



- Persistent sources: low luminosity, small variability
- Transient sources
  - Type I: Series of outbursts ($L<10^{37}$ erg/s) (separate by orbital period)
  - Type II: brighter, long outbursts not related to the orbital period

X Per



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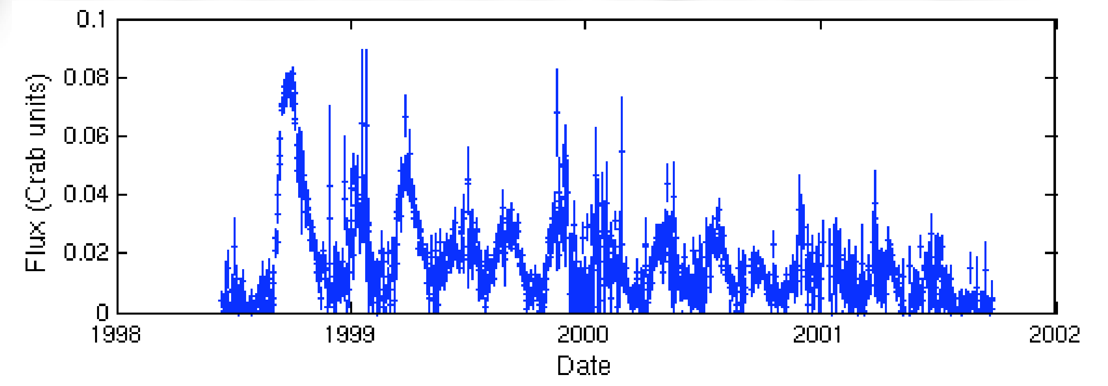
3A 1942+274



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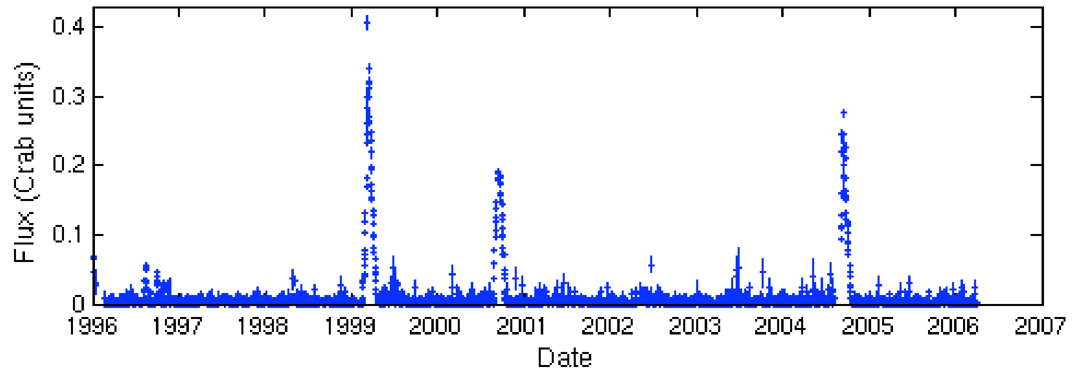
X 0115+634



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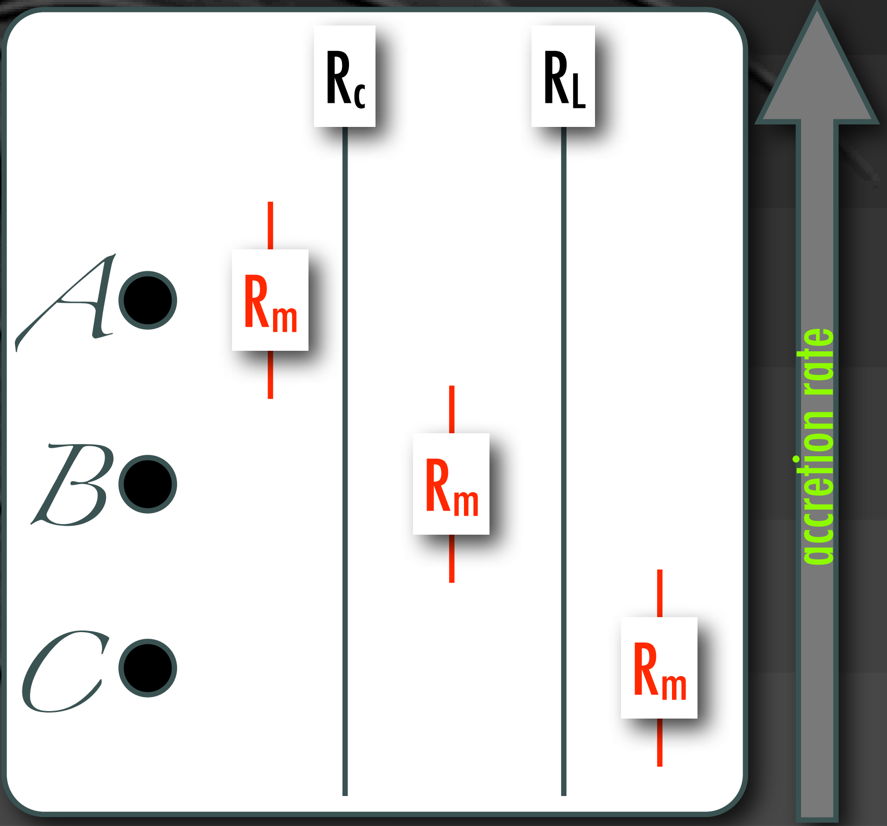
- R_m - Magnetospheric radius: accretion pressure = magnetic pressure
- R_c - Corotation radius: disk rotates with the NS
- R_L - Light cylinder radius: magnetosphere rotates at v=c

R_c & R_L do not depend on accretion.

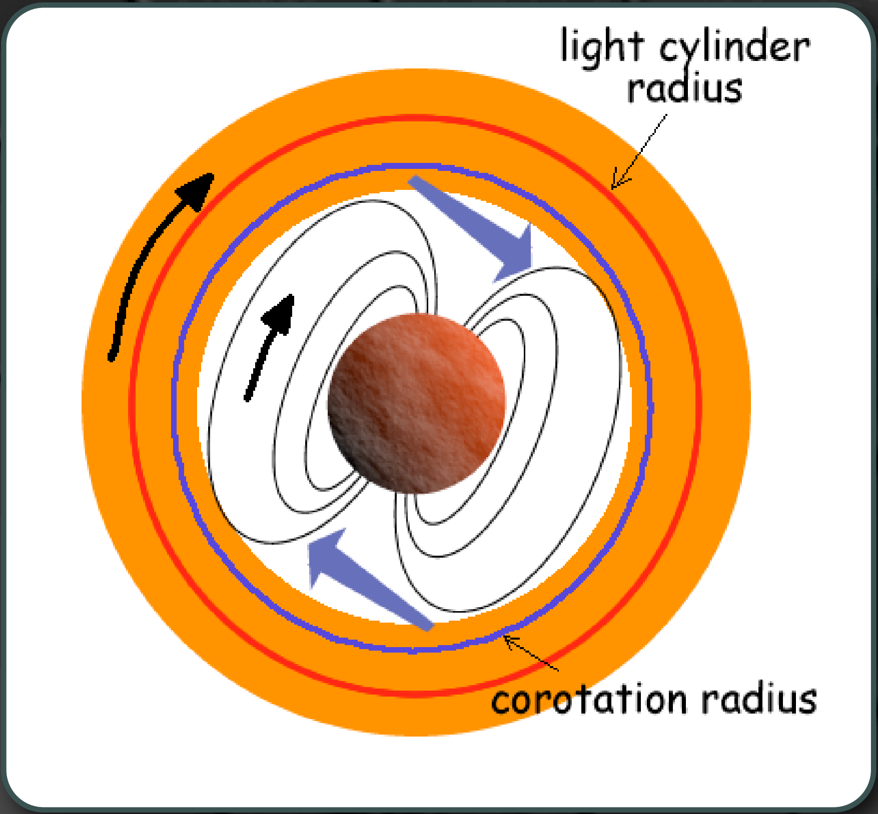
R_m depends on accretion: high accretion rate, small R_m

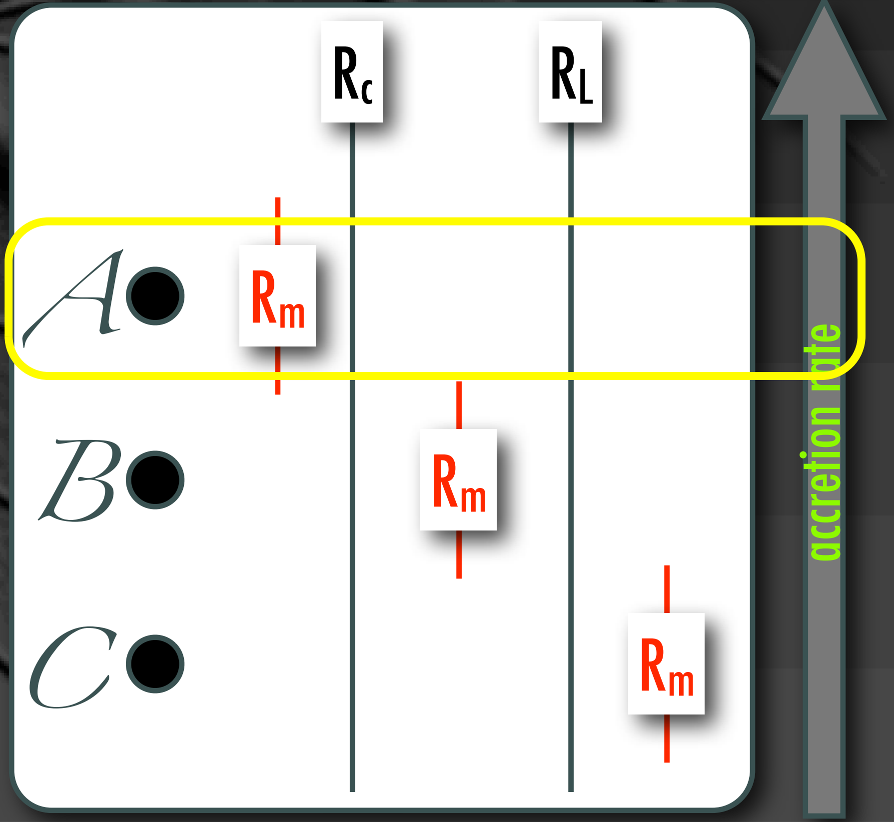


Accretion regime: $R_m < R_c$

Matter can accrete onto the poles

Energy release is $L = GMM/R_*$



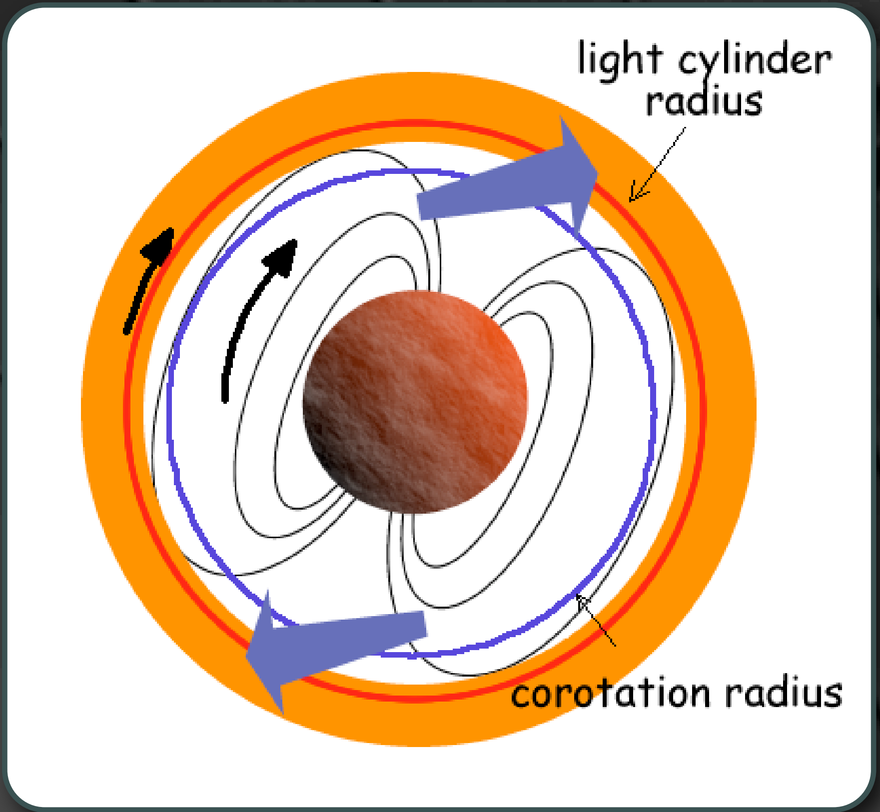


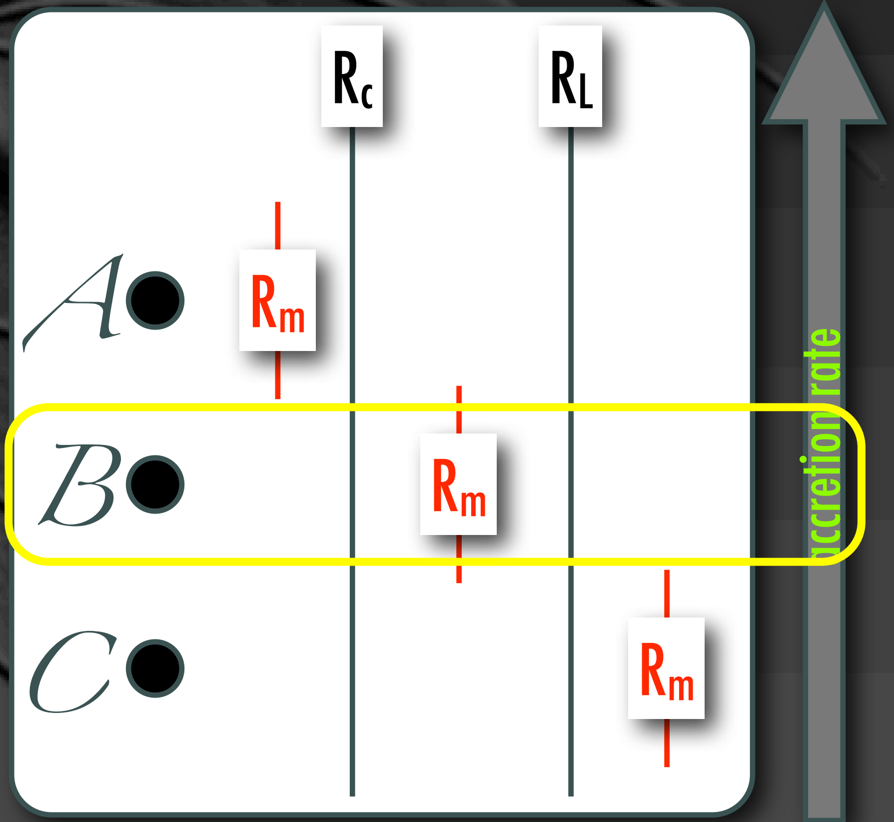
Propeller regime: $R_m > R_c$

Centrifugal barrier (B field stronger than gravity)

Matter accumulates or is ejected from R_m

Accretion onto Rm: lower gravitational energy released

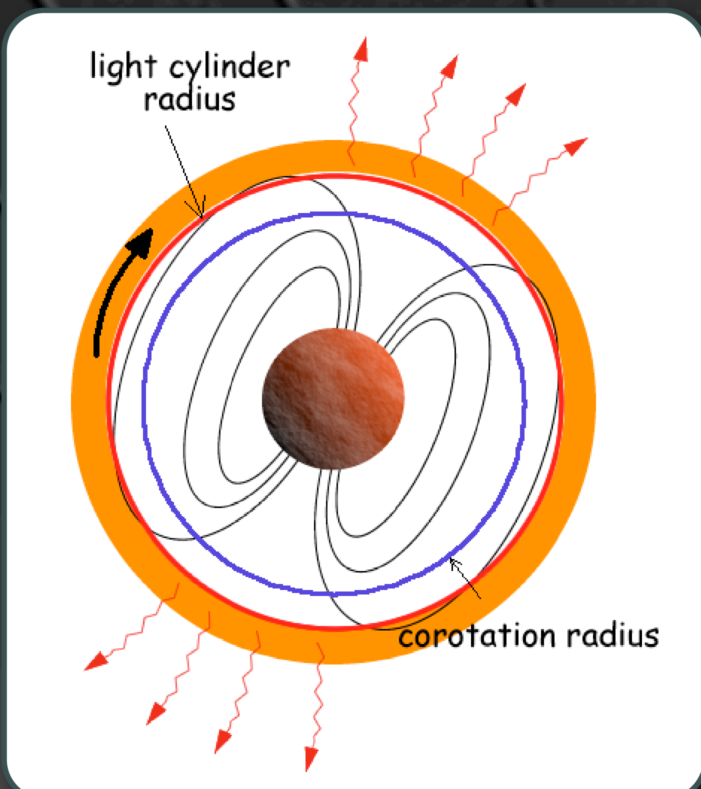


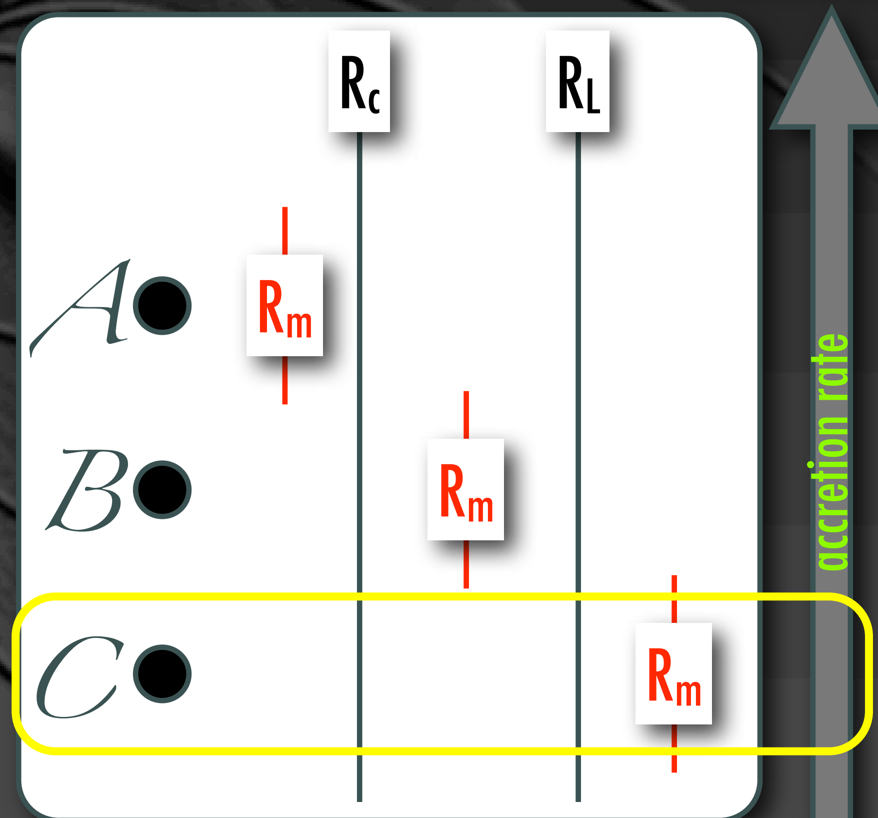


Radio pulsar regime: $R_m > R_L$

No accretion possible

Disk matter is swept away by pulsar wind and pressure

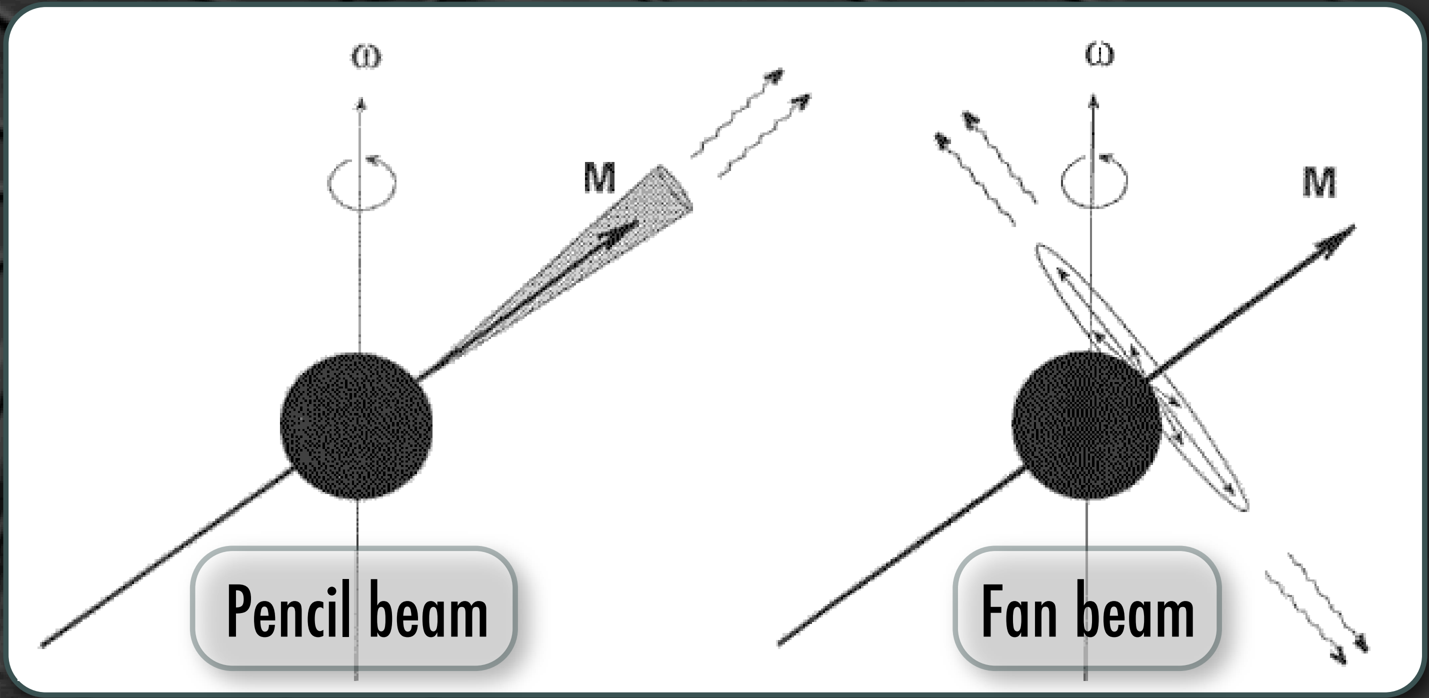




Low accretion: pencil beam
High accretion: fan beam

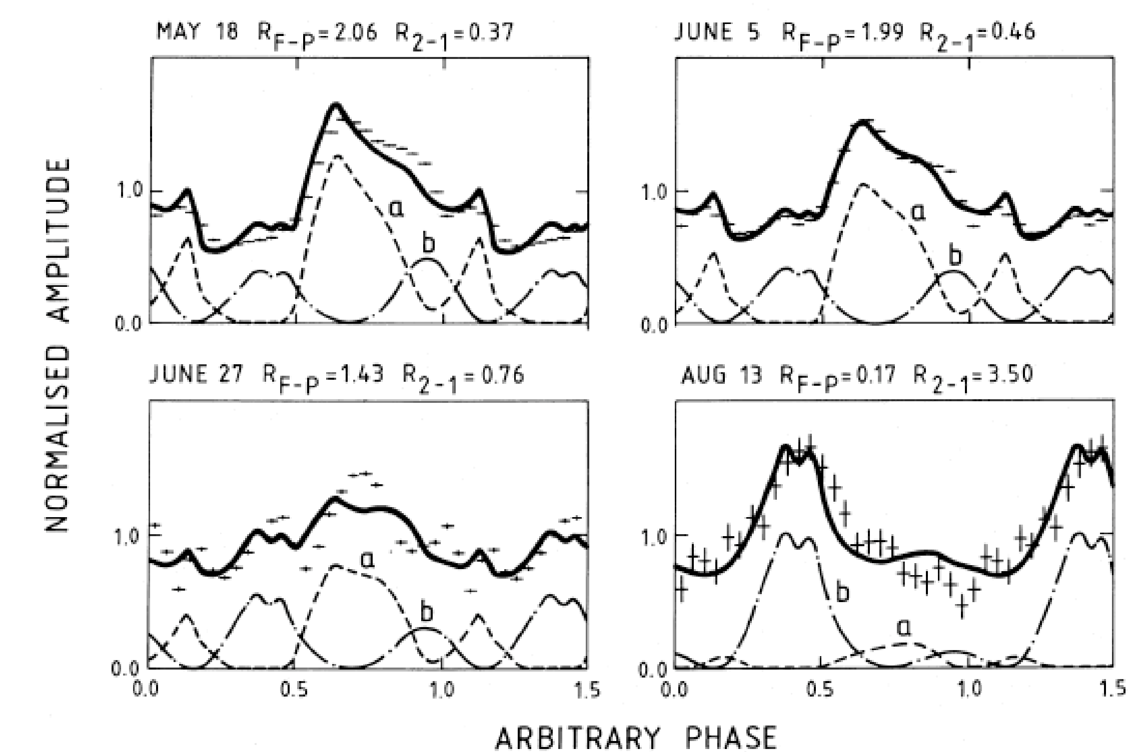
Reality: very complicated

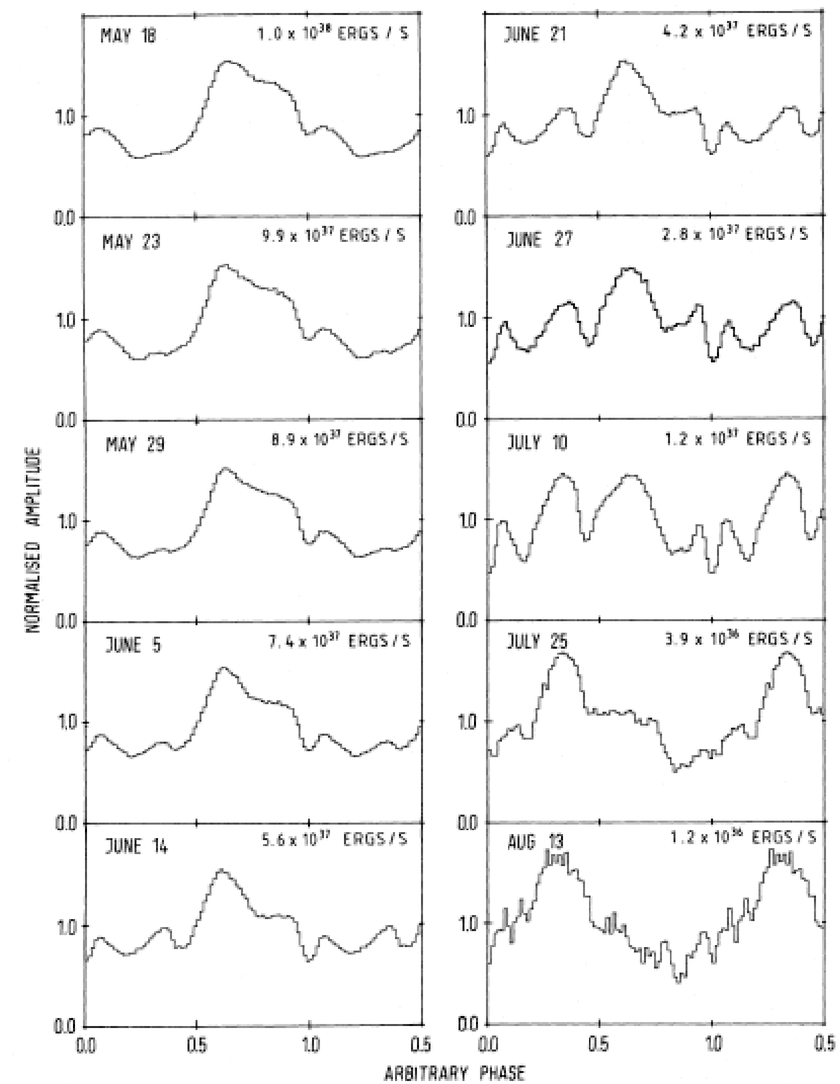
Pulse shape: depends on luminosity and energy



EXO 2030+375

Luminosity dependence



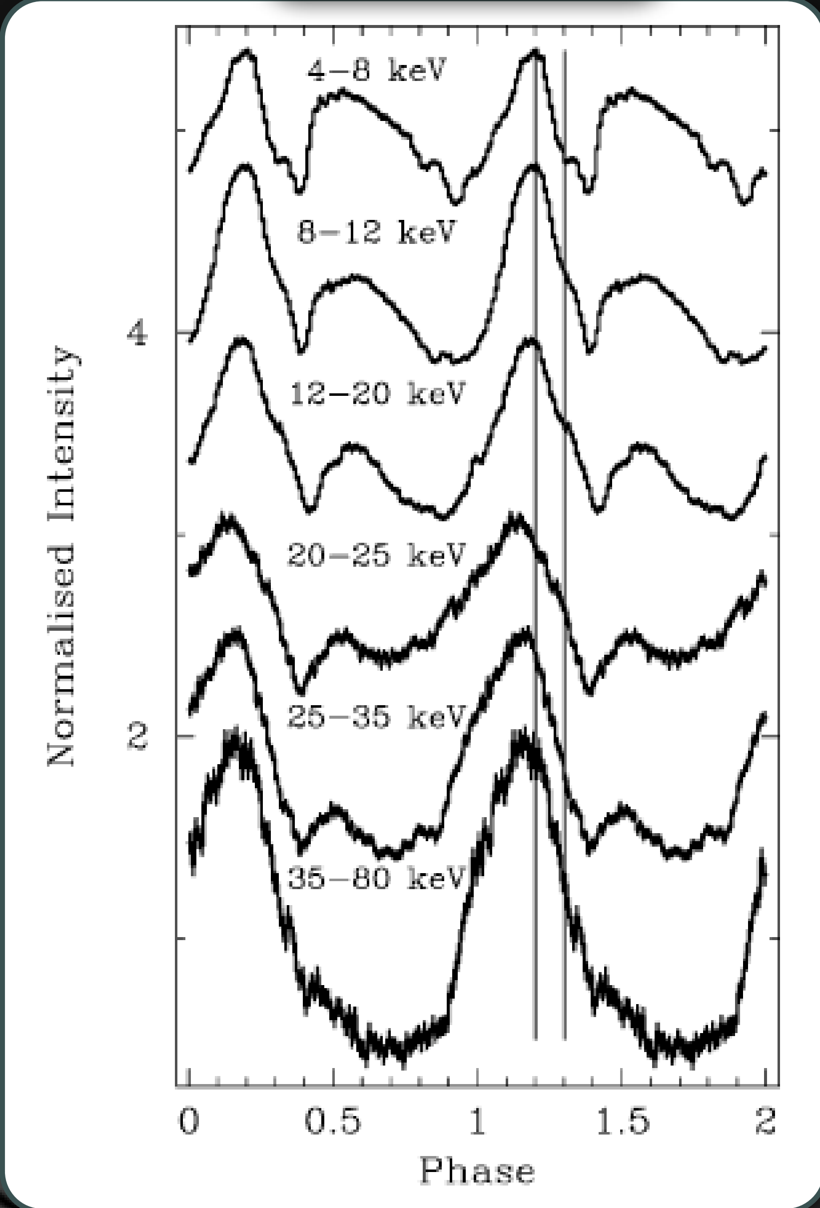


Parmar et al. (1989)

X 0115+634

Energy dependence

Pulse phase spectroscopy



Santangelo et al. (1999)

Magnetospheric radius

$$r_m = \xi r_A = \xi(\frac{\mu^4}{2GM_X\dot{M}^2})^{1/7}$$

Corotation radius

$$r_c = (\frac{GM_X P_{spin}^2}{4\pi^2})^{1/3}$$

Disk torque

$$N \sim \dot{M}\sqrt{GM_X r_m}$$

Pulsar spins up until

$$r_m \sim r_c$$

Equilibrium period

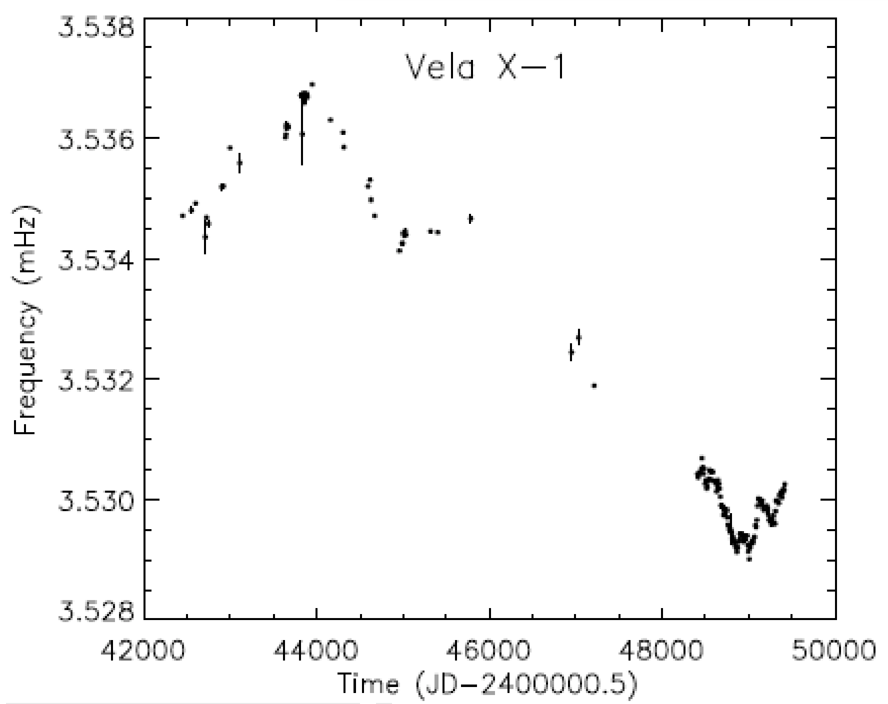
$$P_{eq} \sim 8s(\frac{10^{-10}M_\odot yr^{-1}}{<\dot{M}>})^{3/7}(\frac{\mu}{10^{30}Gcm^3})^{6/7}$$

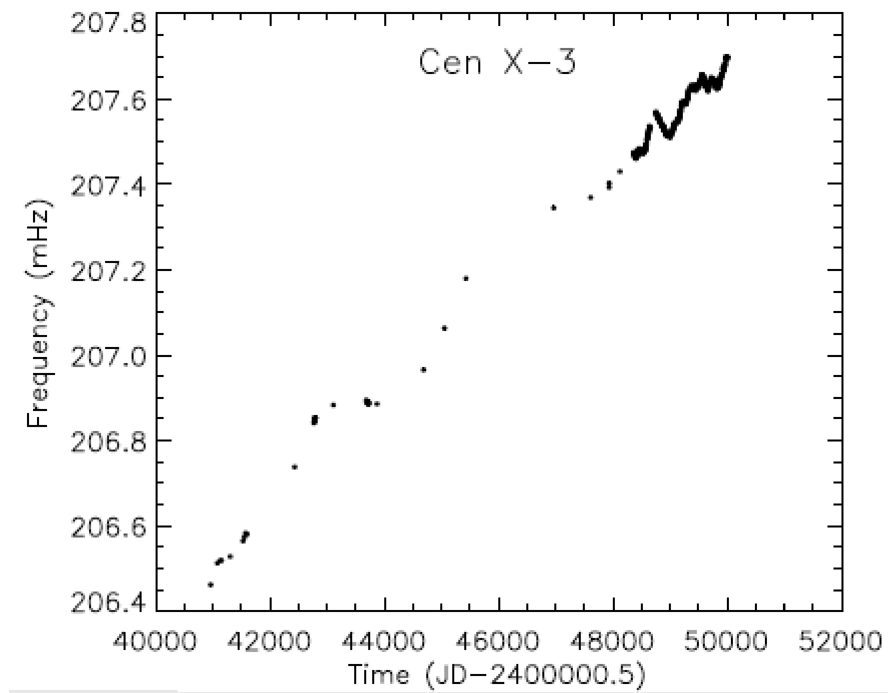
On a time scale much shorter than the system's age

We should see the systems spin up

Spin-up & spin-down

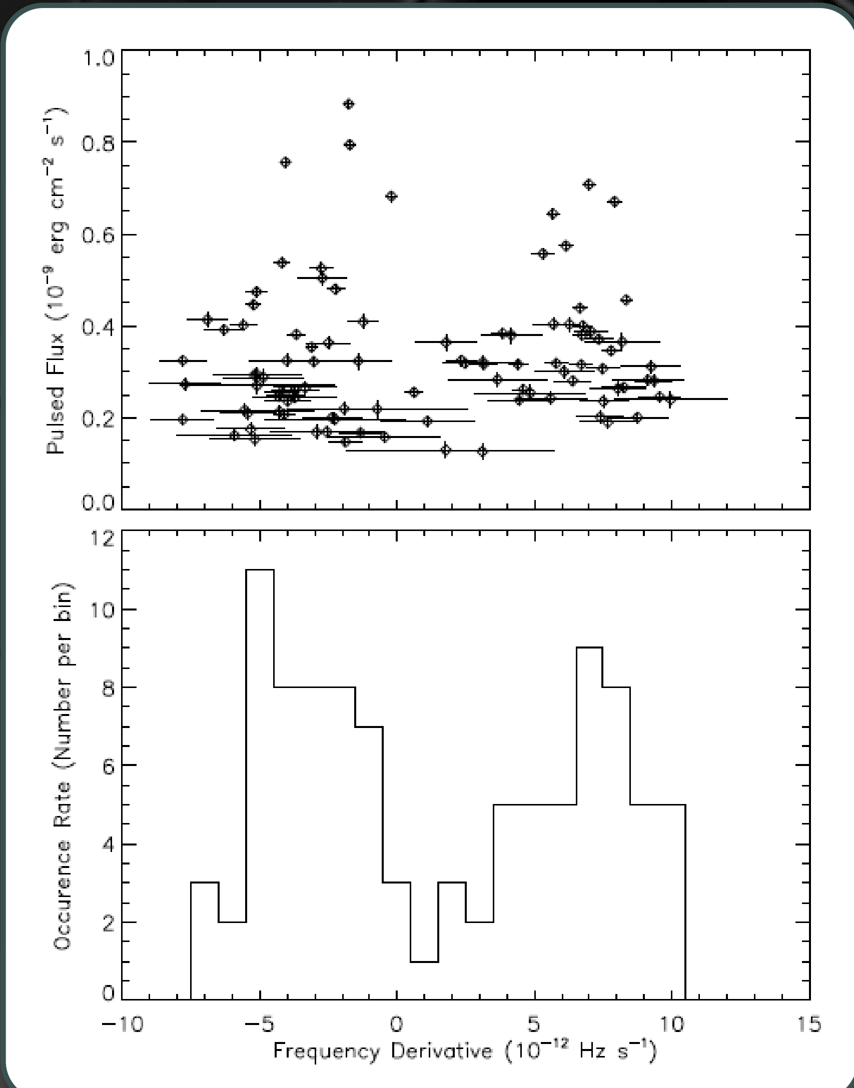
Bildsten et al. (1997)

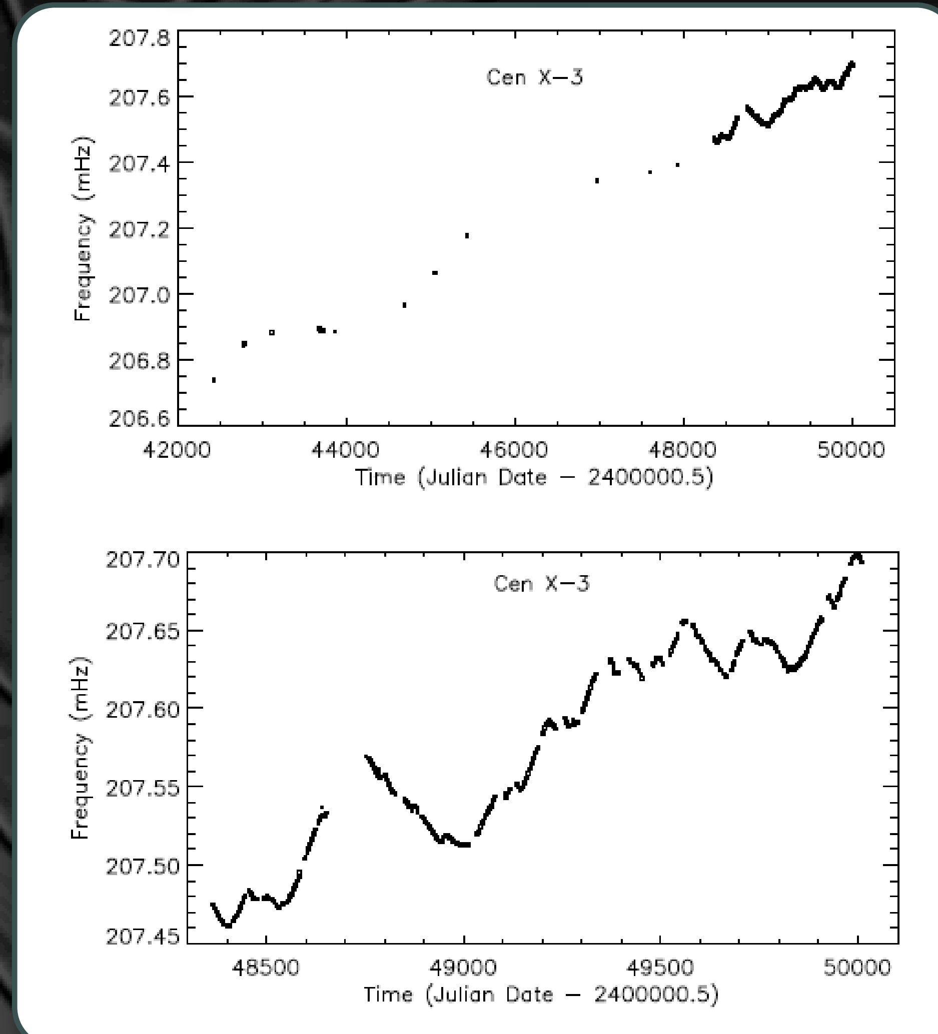




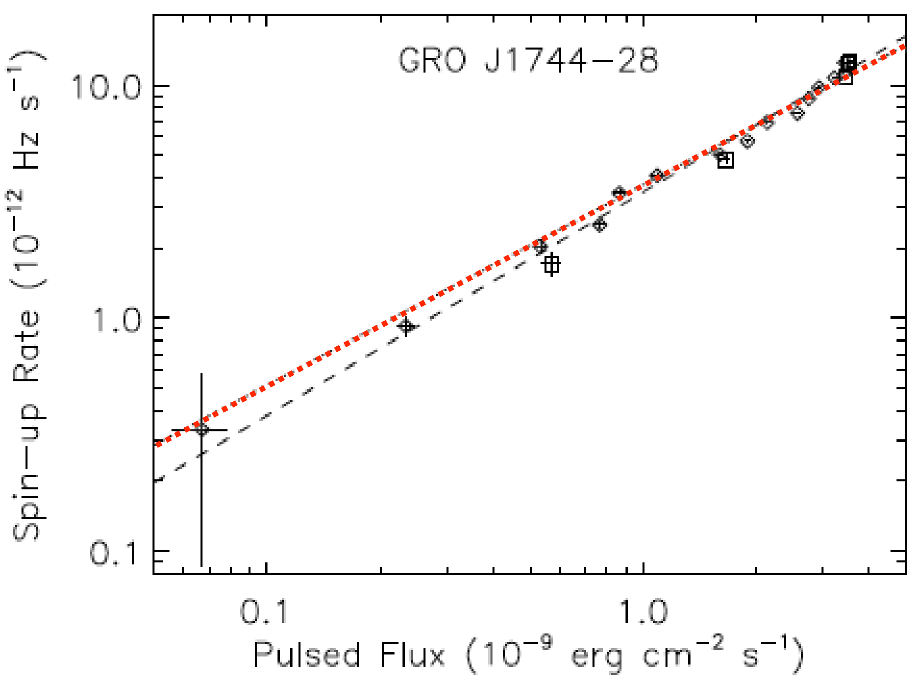
- Spin-down problem
- Spin-up rate problem

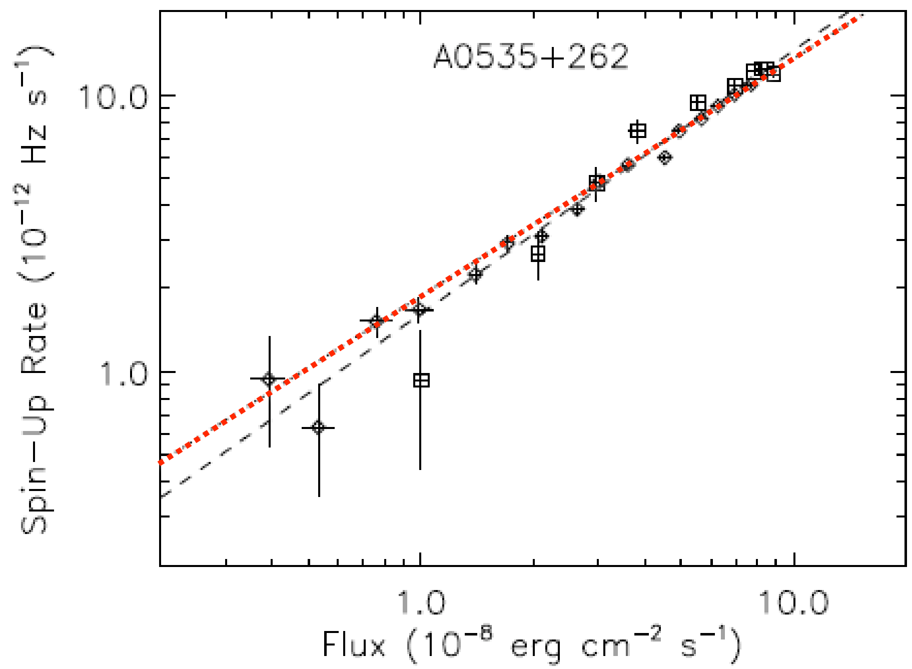
Need short-term measuremens





Bildsten et al. (1997)





Expectation

$$\dot{\nu} \propto \dot{M}^{6/7}$$

Bildsten et al. (1997)

Energy Spectra of X-ray pulsars

Different models proposed for the continuum

- Power law + cutoff — White et al. (1983)
- Broken power law — Mihara et al. (1999)
- More complex

Spectrum is indeed complex and broad-band

Energy Spectra of X-ray pulsars

Pulse-averaged spectrum

- A soft (reprocessed) 0.1 keV blackbody
- A power law with high-energy cutoff @15-20 keV
- An exponential roll-off above E_{CUT}
- Emission lines (iron 6.4 keV but not only)
- Cyclotron absorption features

Cyclotron absorption lines

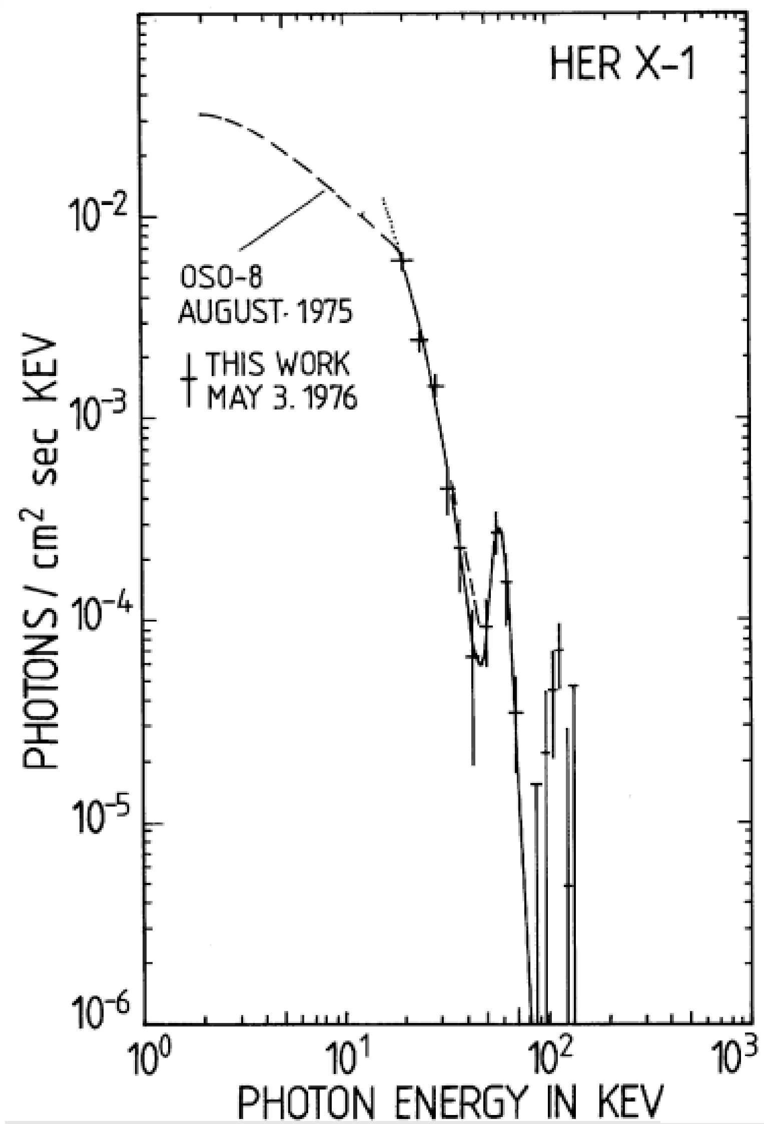
First discovery: Her X-1

Energy depends on B field

$$E_{cyc} = 11.6 B_{12} (1+z)^{-1} \text{ keV}$$

$$(1+z)^{-1} = \sqrt{1 - \frac{2GM}{Rc^2}}$$

Cyclotron resonant scattering

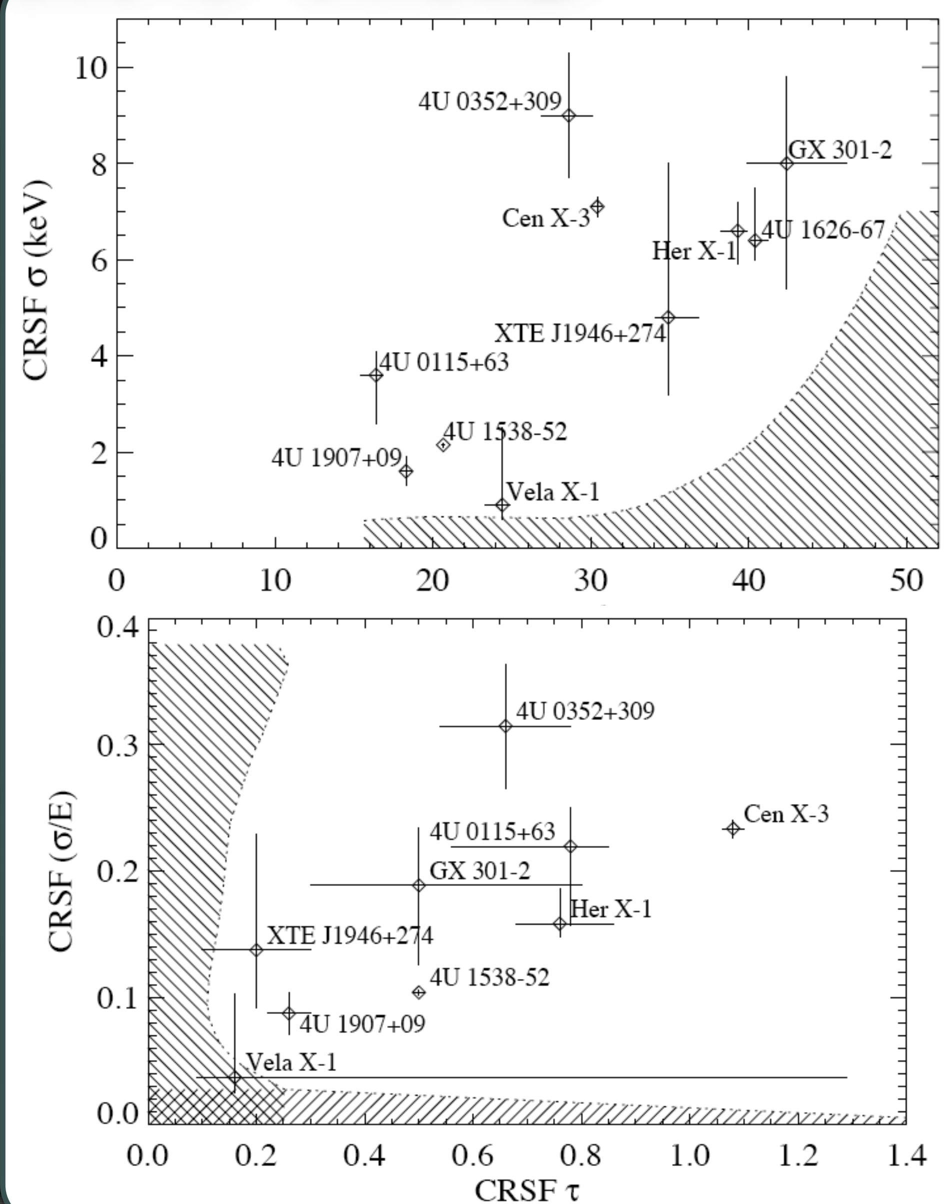


Trümper et al. (1978)

Cyclotron absorption lines

Now seen in many systems (RossiXTE, BeppoSAX)

Variations with the pulse also seen



Coburn et al. (2002)

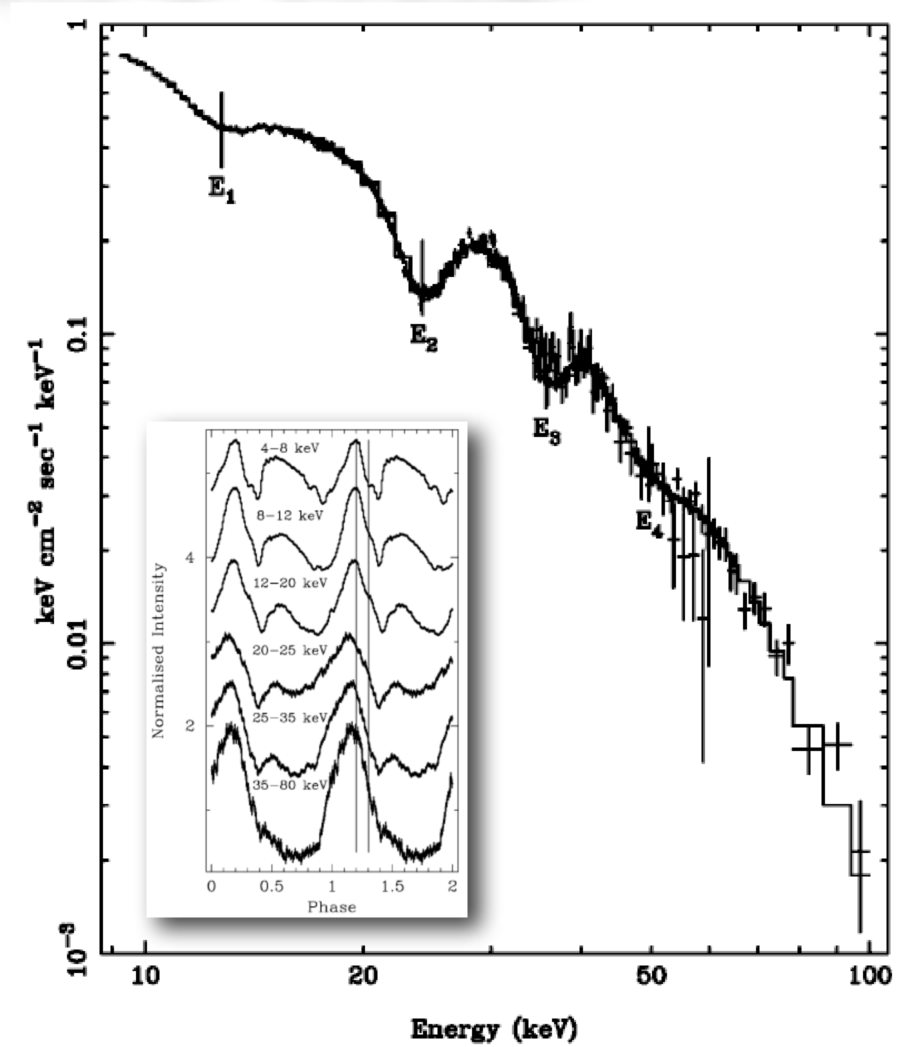
Cyclotron absorption lines

X 0115+634

Harmonics

Confirmation of their origin

Eqw of higher harmonics larger than fundamental: 2-photon effects dominate



Santangelo et al. (1999)

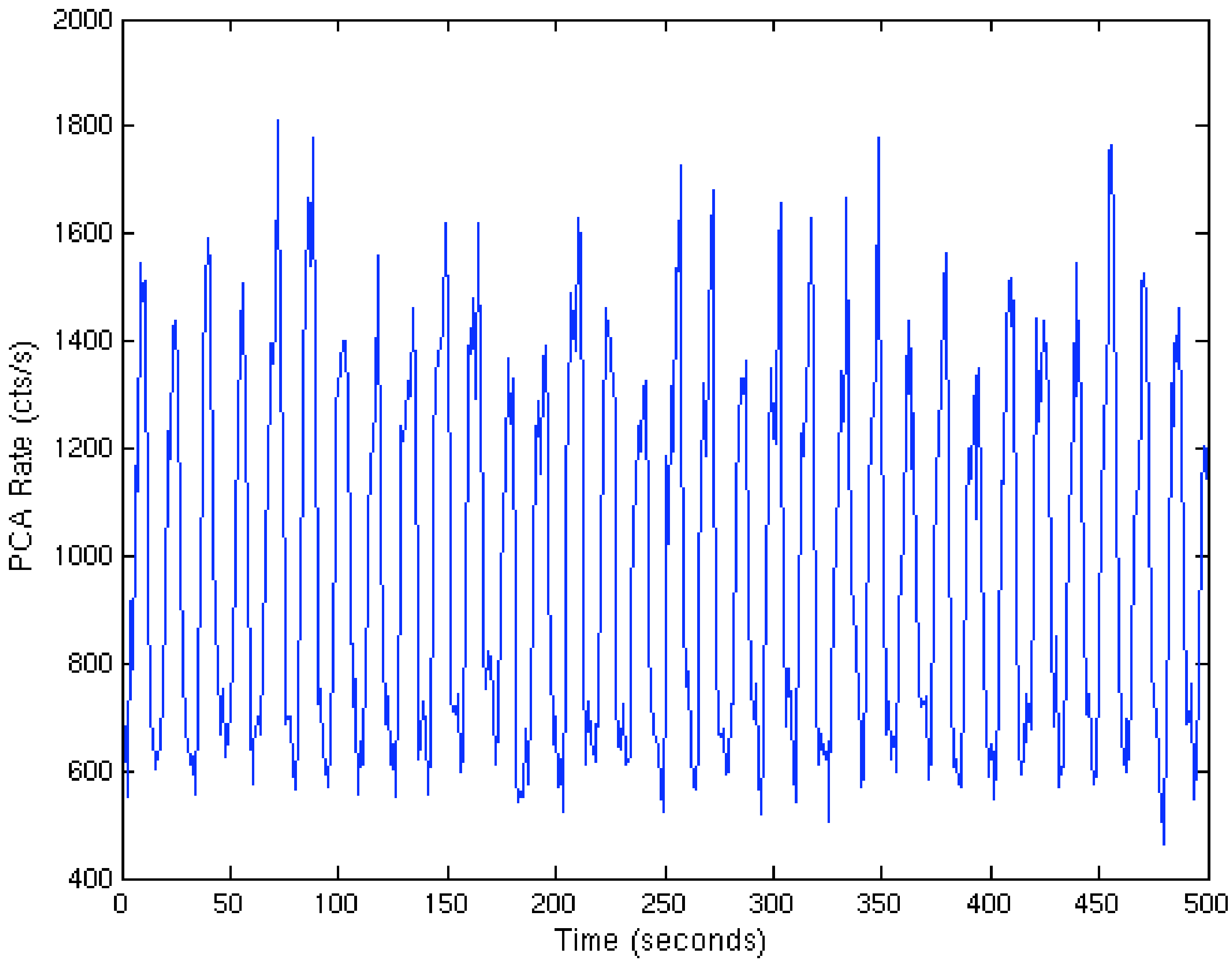
What I did not touch

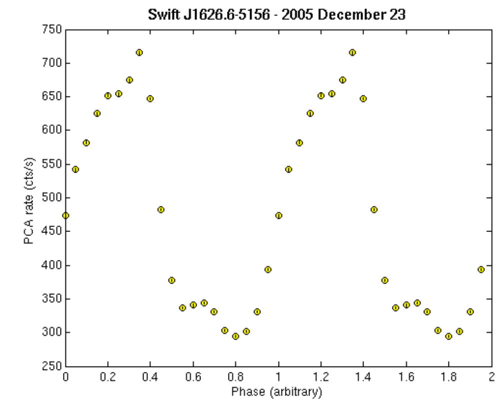
- Complex sources such as Her X-1 & LMC X-4
- Pulse period noise
- The bursting pulsar GRO J1744-28

Recently (December 2005), new strange system

Swift J1626.6-5156

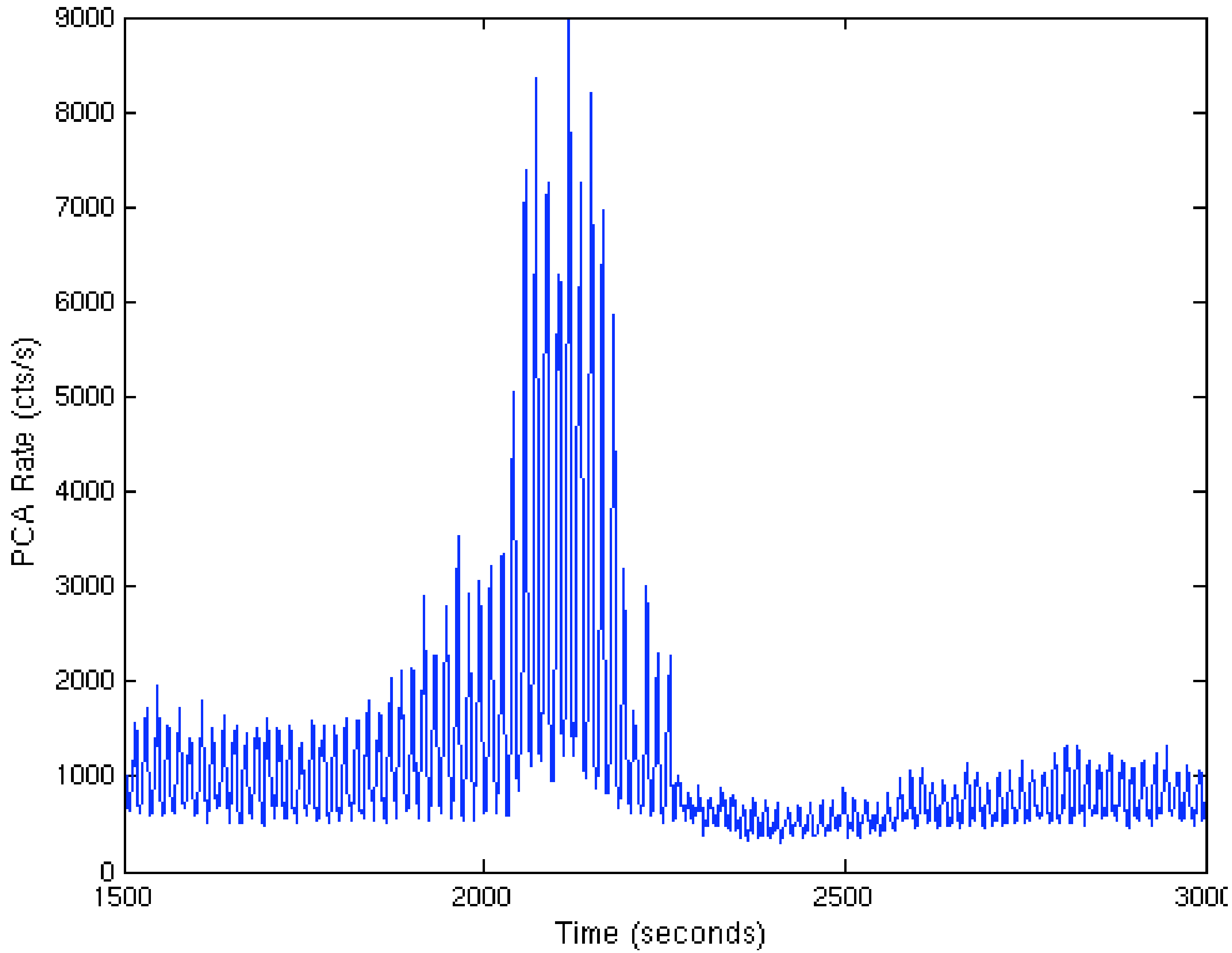
Swift J1626.6-5156

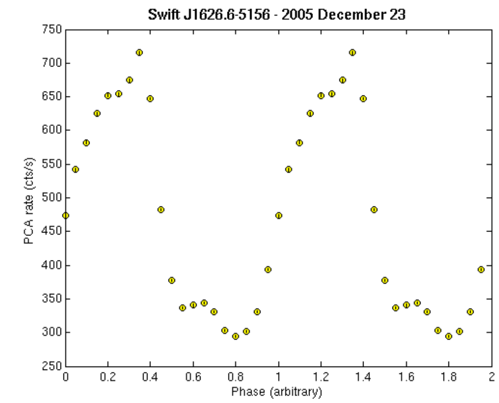




Belloni et al. (2006)

Swift J1626.6-5156





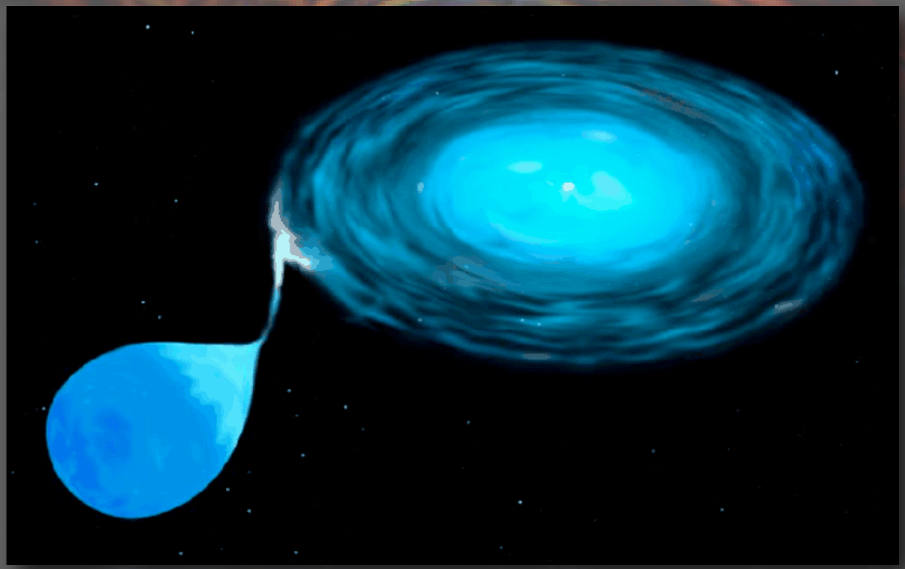
Belloni et al. (2006)

NS LMXB

Low-B NS X-ray binaries

- Magnetic field 10^8-10^9 G
- Some are (ms) pulsars, most are not
- Late spectral type companion
- Accretion disk extends closer to the NS
- Inner disk region: GR effects

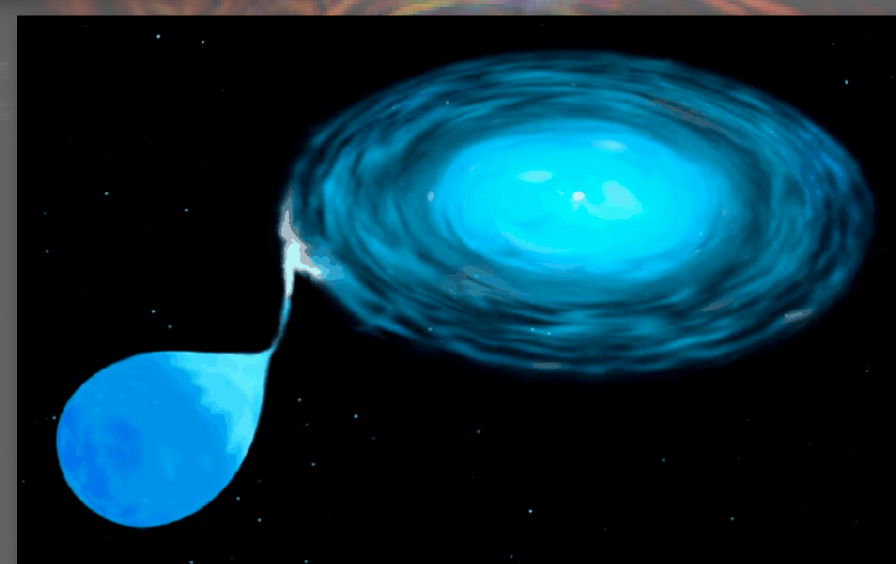
See black holes



BH X-ray binaries

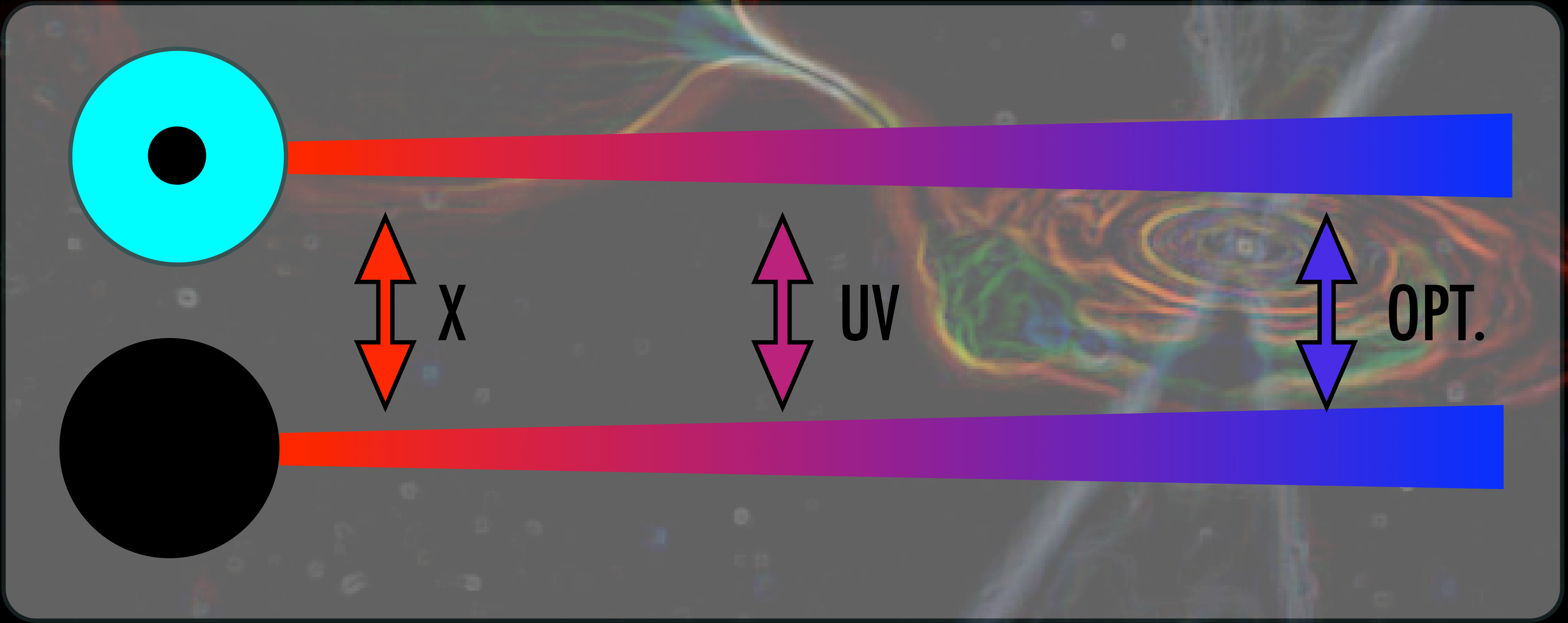
- No magnetic field
- None are pulsars
- Late spectral type companion (but not only)
- Accretion disk extends closer to the BH
- Inner disk region: GR effects

See neutron stars

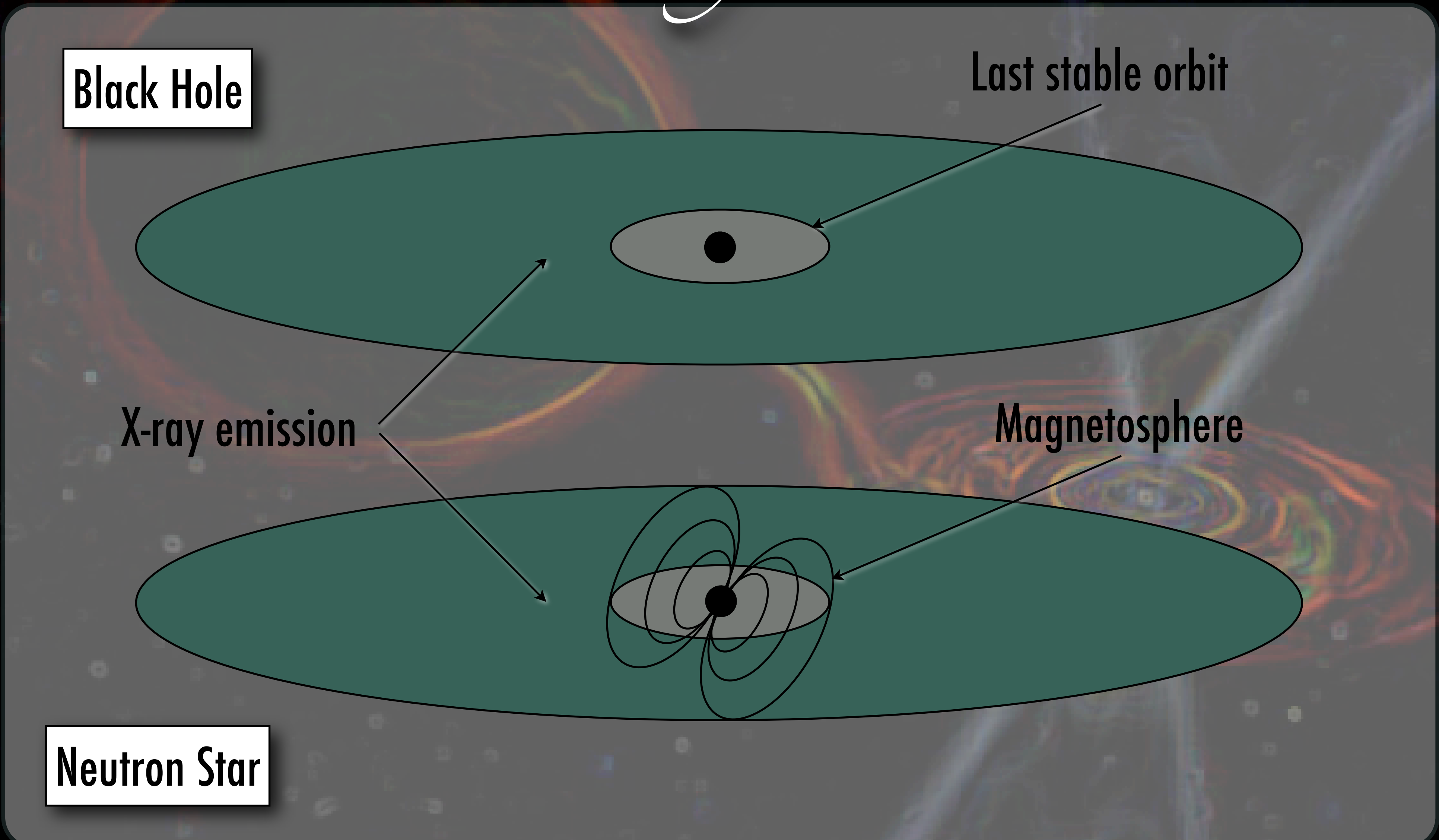


BH / NS X-ray binaries

- Accretion disk structure
- Black hole or neutron star?

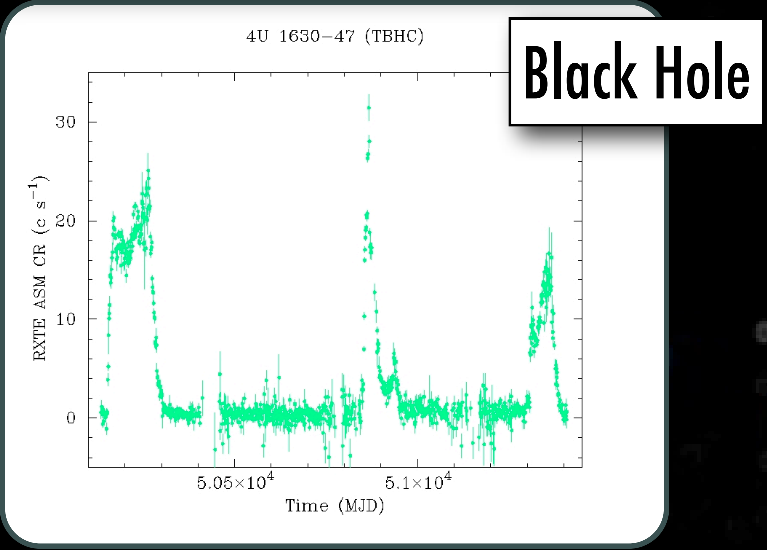


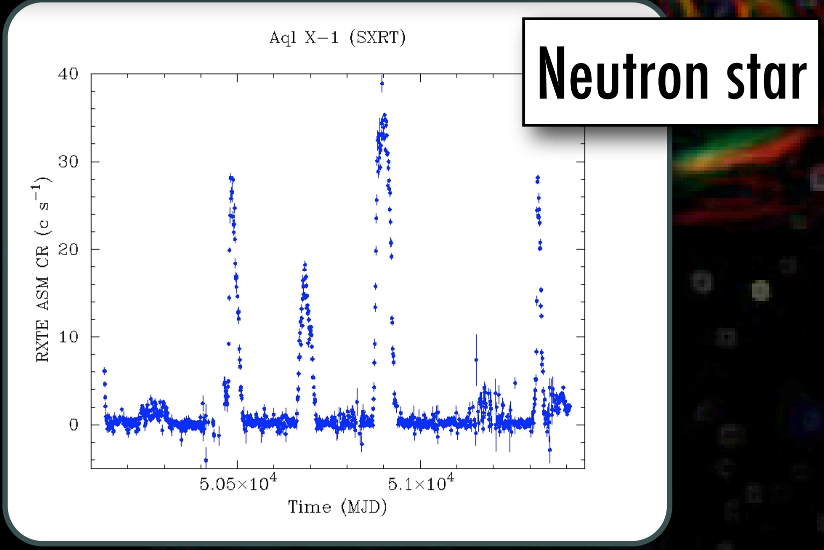
BH / NS X-ray binaries



The role of accretion rate

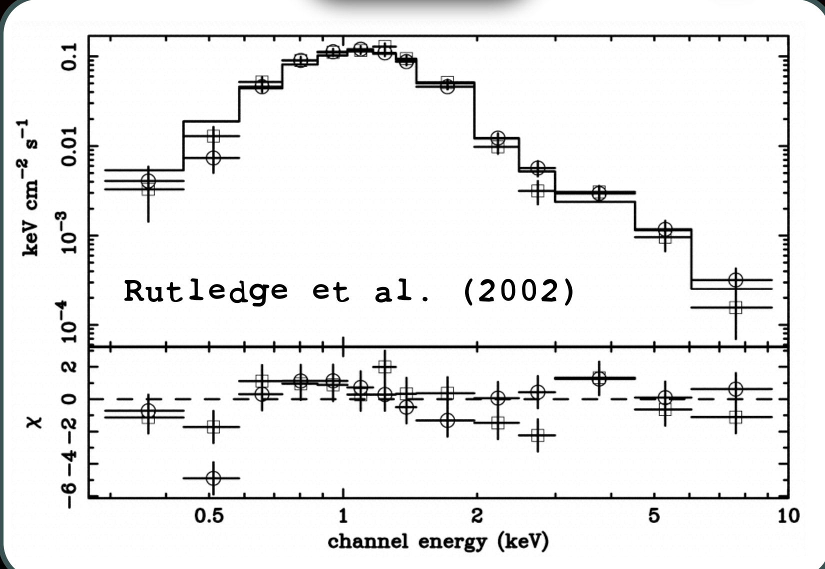
- Accretion rate as main parameter
- Many systems are observed as transients
  - Quiescence: low accretion rate ($L_X = 10^{30-33}$ erg/s)
  - Outburst: large accretion rate ($L_X = 10^{37-39}$ erg/s)
  - Important to study accretion rate range



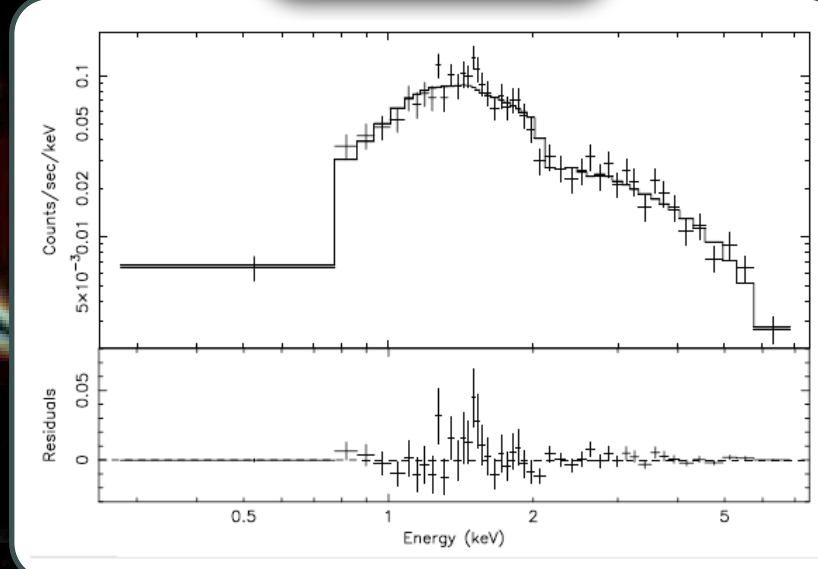


BH/NS in quiescence

NS: Aql X-1



BH: GS 2023+338



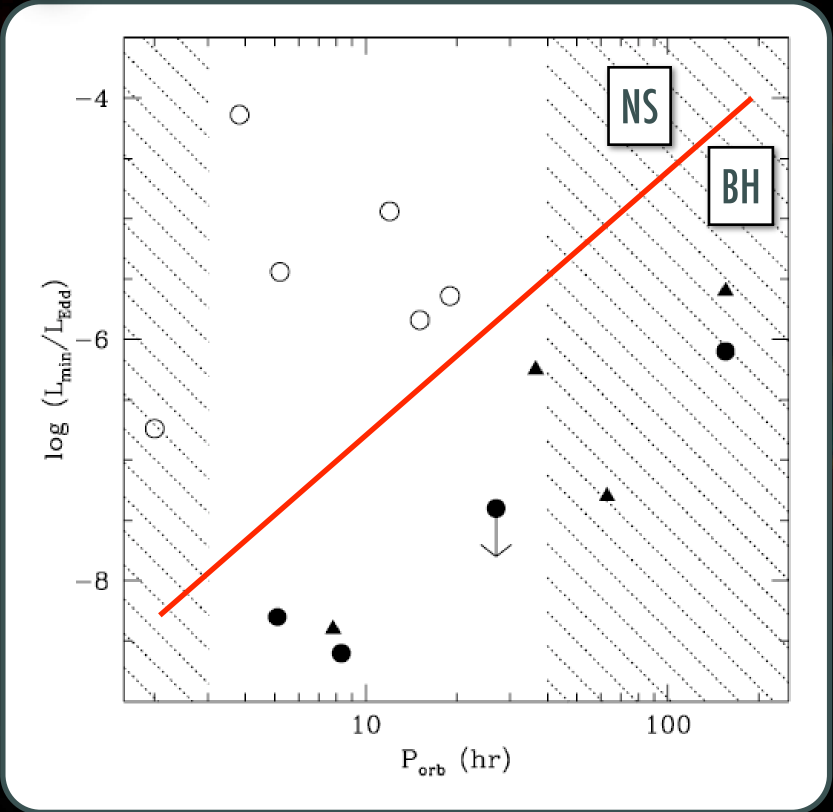
- "Canonical" NS spectrum
- BB/NS Atm., kT=0.1-0.3 keV

  plus
- Power law, photon index 1-2

- BHC spectrum
- Power law, photon index 1-2

  or
- Optically thin plasma, kT=2-3 keV

Quiescent luminosity

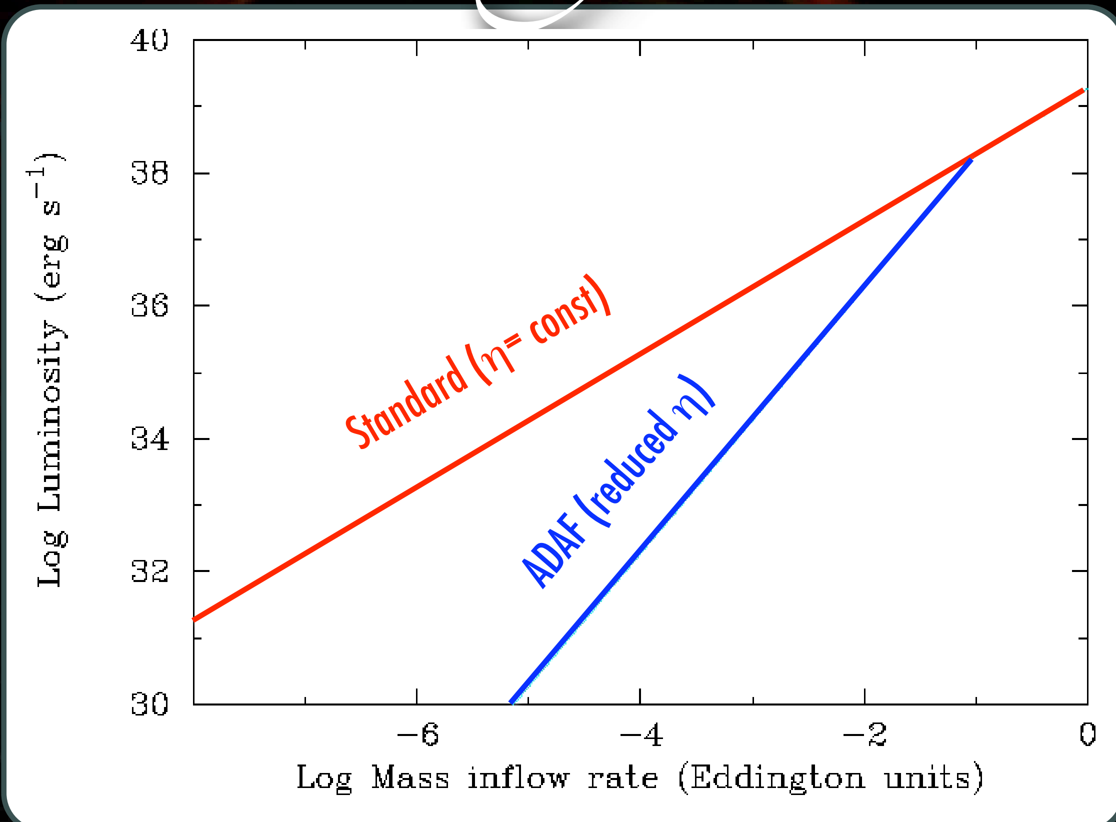


- Clear segregation in L_X
- Larger min-max L swing in BH than NS

Similar binaries: similar swing in mass inflow rate expected

Different mass-to-radiation conversion efficiency?

Advection flows



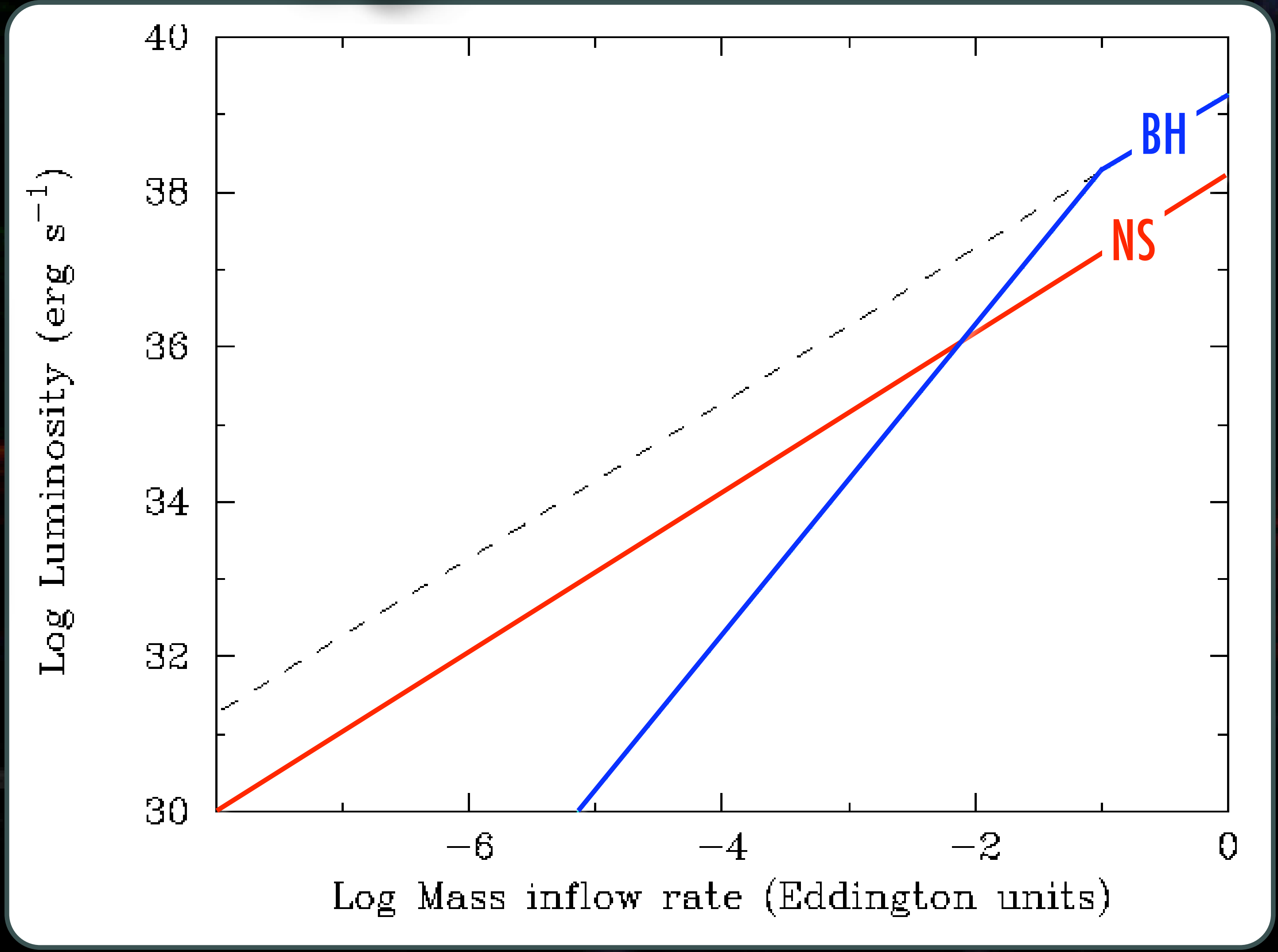
$L = \eta \dot{M} c^2$ mass-to-radiation conversion efficiency

For low rates, increasing fraction of energy stored in the accretion flow

- In BH: energy “lost” in the horizon (reduced efficiency)
- In NS: energy is release at the surface (standard efficiency)

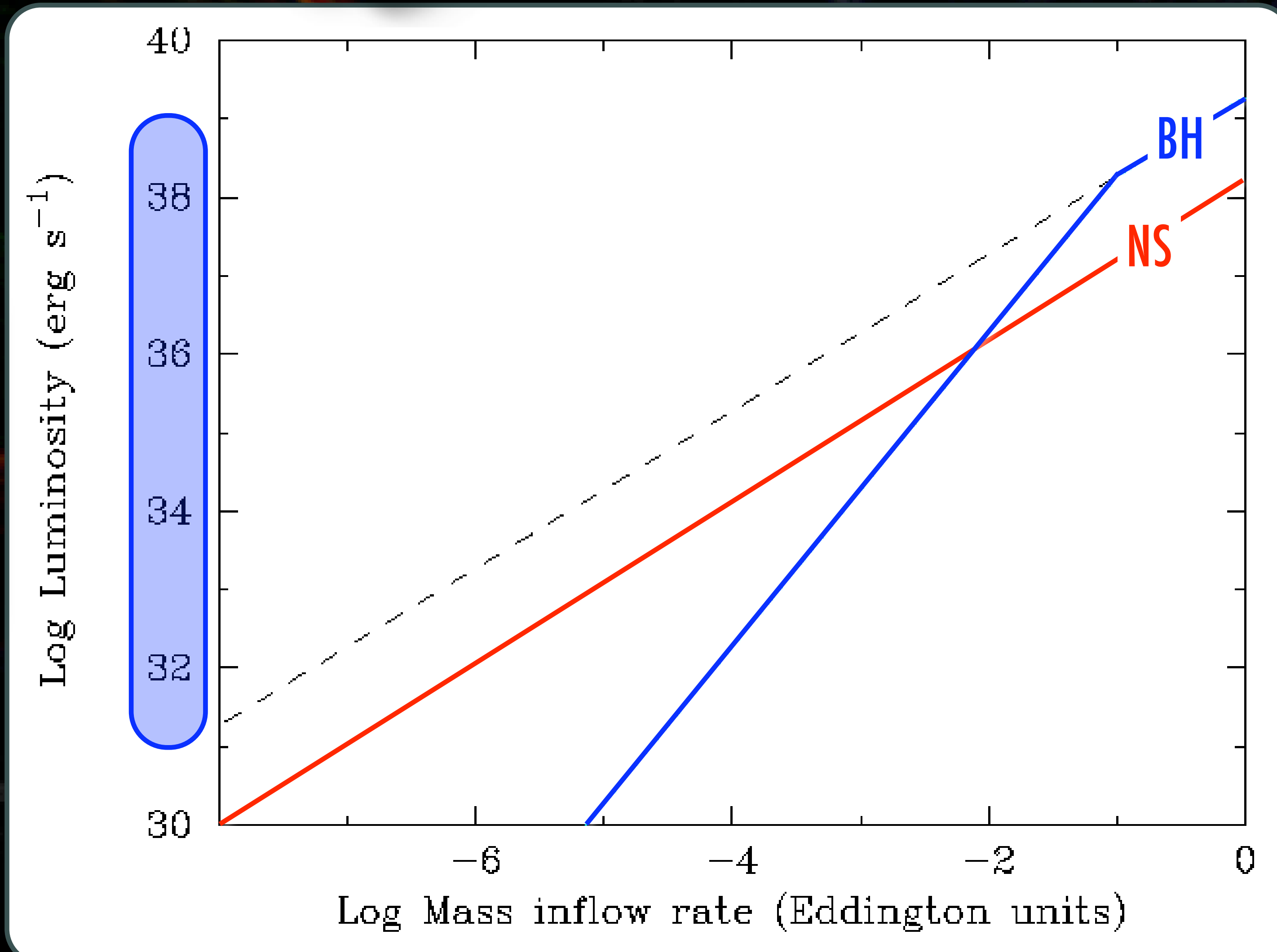
The larger swing for BH

Something more is needed



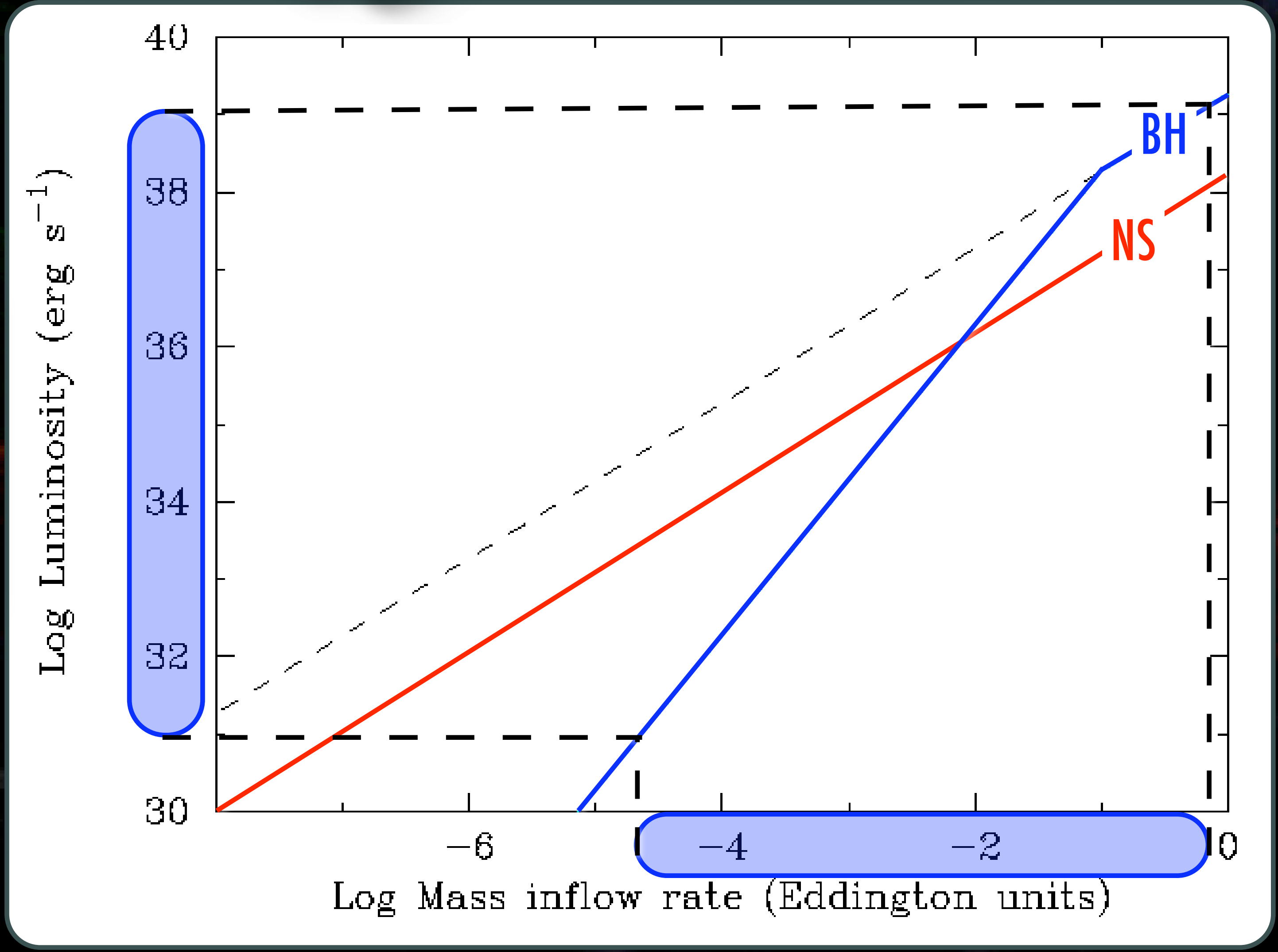
The larger swing for BH

Something more is needed



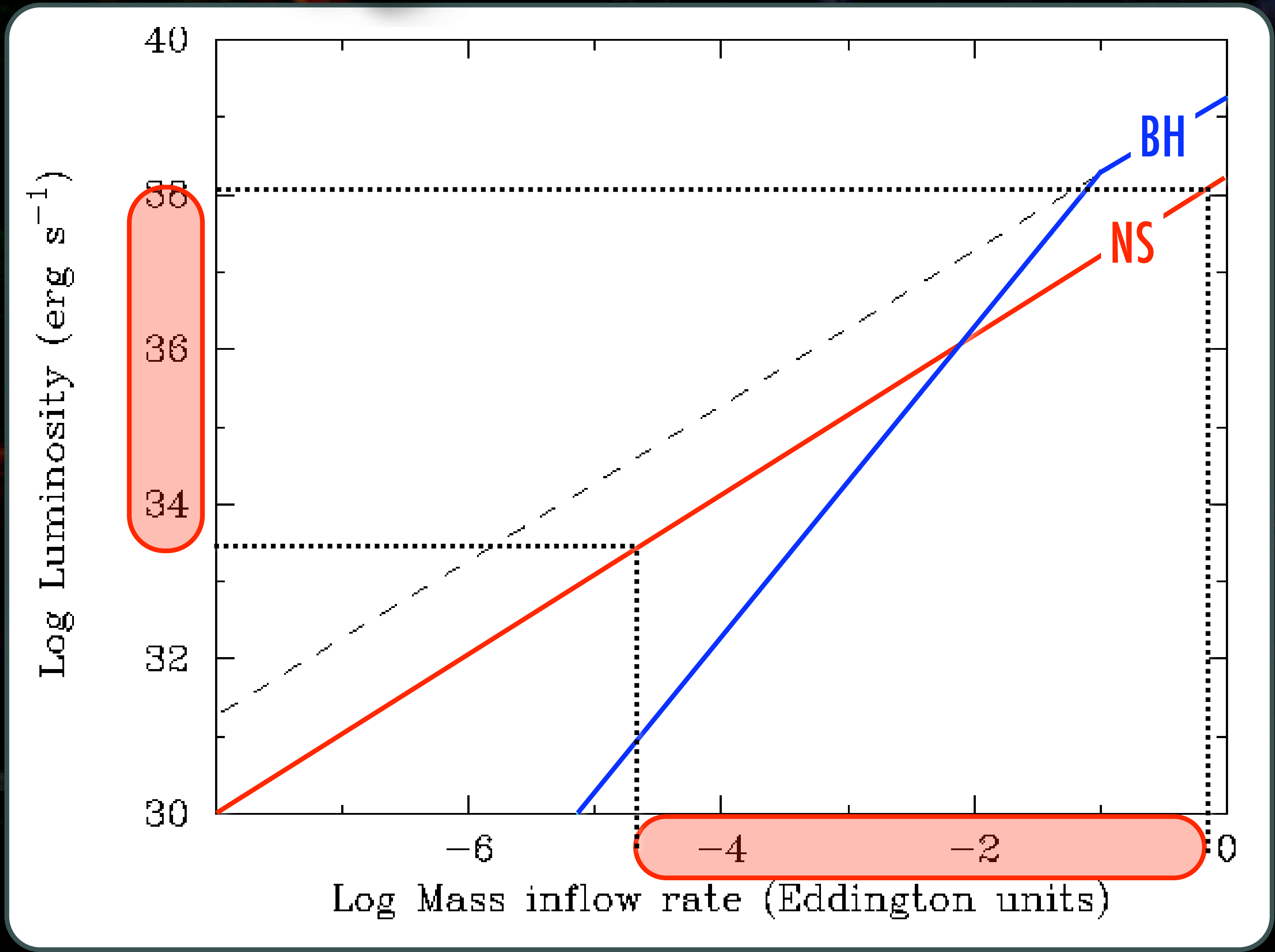
The larger swing for BH

Something more is needed



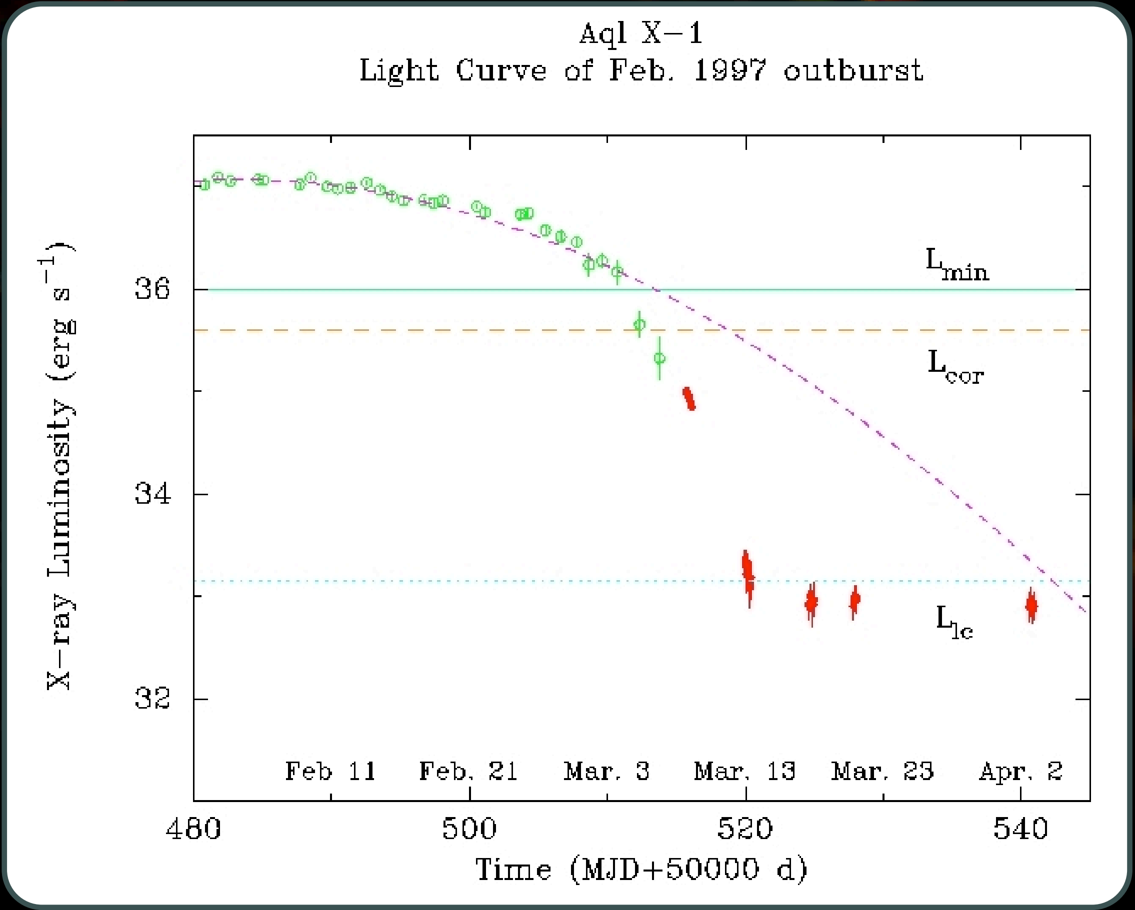
The larger swing for BH

Something more is needed



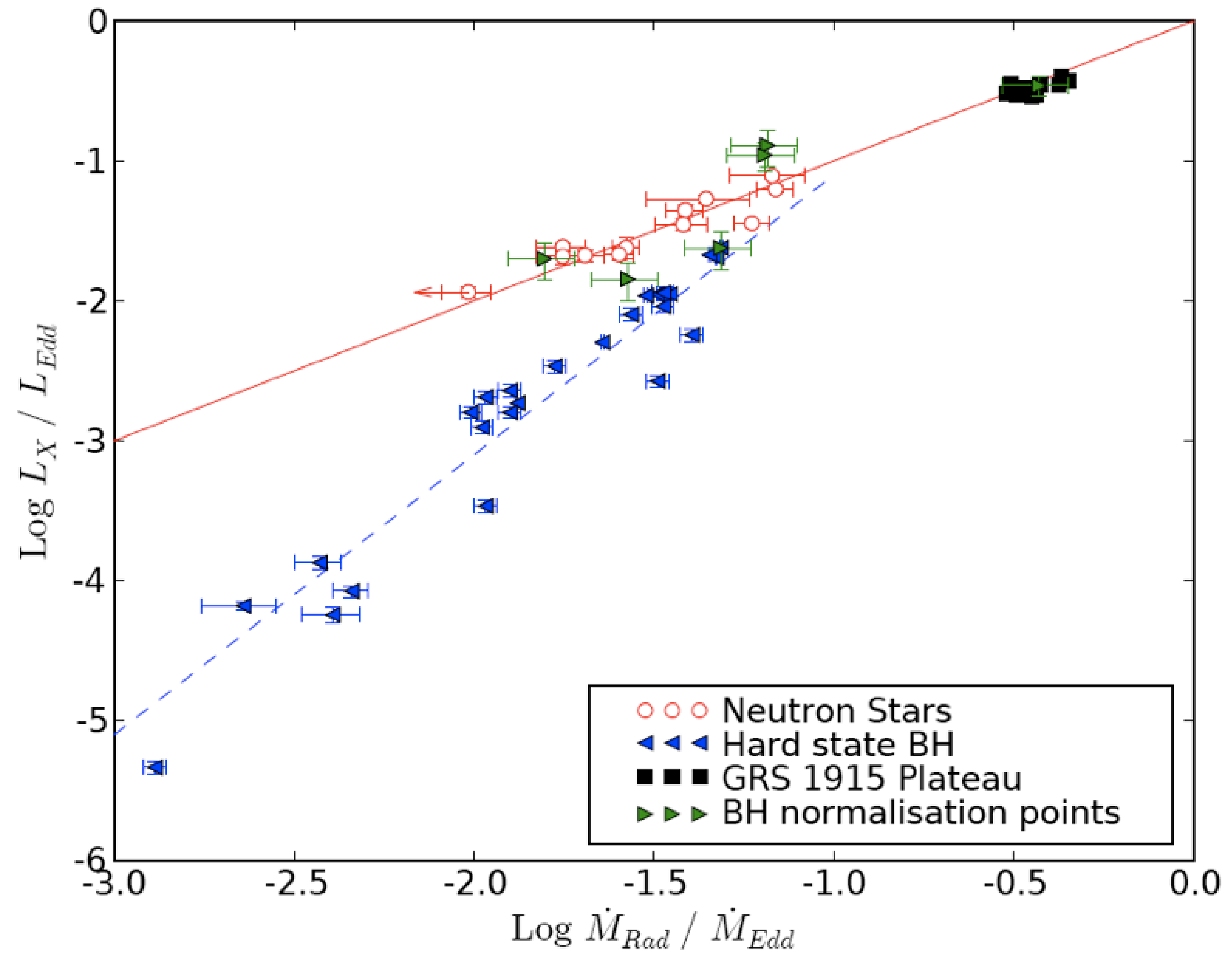
Propeller effect for NS?

Campana et al. (1998)



From outburst to quiescence

Jet-dominated advective flows



Körding et al. (2006)

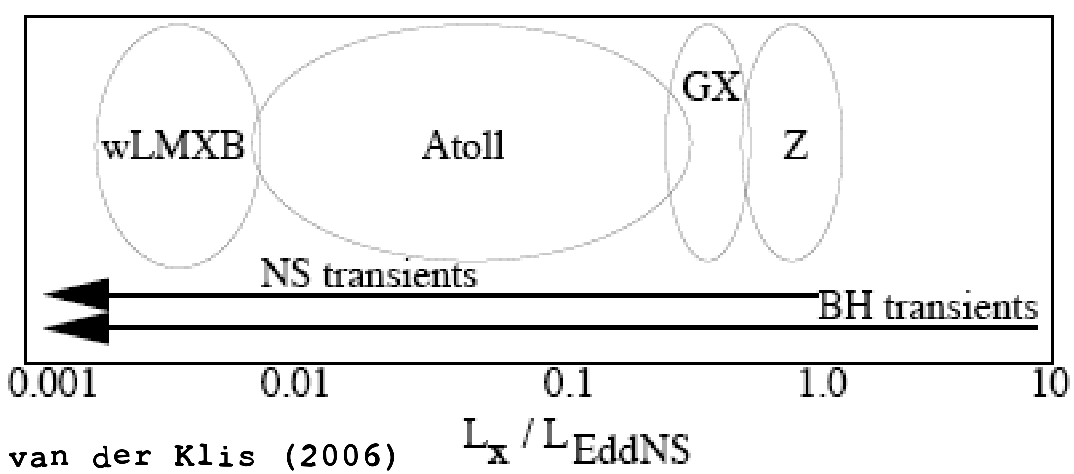
Accretion rate from radio

$$L_{rad} \propto \dot{M}^{1.4}$$

Independent of X rays

NS LMXB: source classes

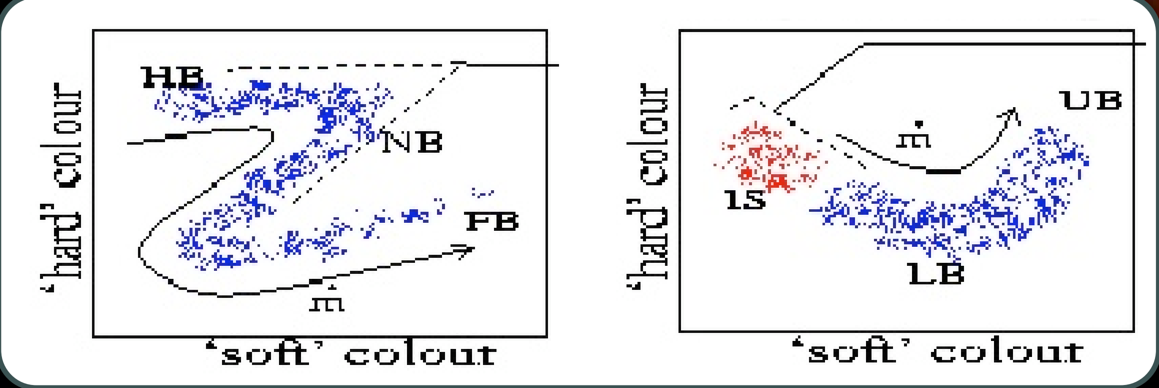
- Z sources
- Atoll sources
- Low-luminosity bursters
- Accreting millisecond pulsars
- Oddballs (Circinus X-1)



van der Klis (2006)

NS LMXB: source classes

- Weakly magnetic systems
- Fast spinning NS (few msec)
- Characteristic phenomena: X-ray bursts
- Fast aperiodic timing (II lecture)
- Source classes



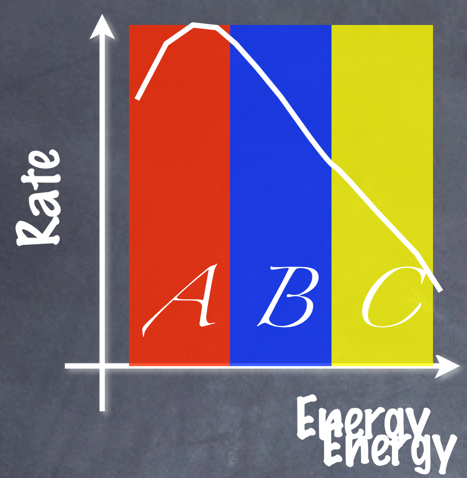
Z source

Atoll source

- Z sources
  - LX 0.1-1.0 LEDD
  - All persistent (?)
- Atoll sources
  - LX 0.01-1.0 LEDD
  - Some transient
  - type-I bursts
- Low-L bursters
  - LX <0.01 LEDD
  - Some transient
  - type-I bursts

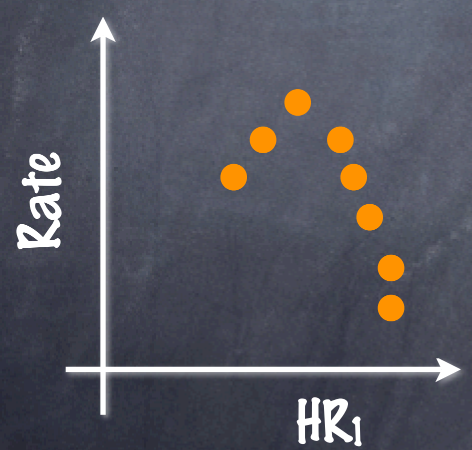
accretion rate

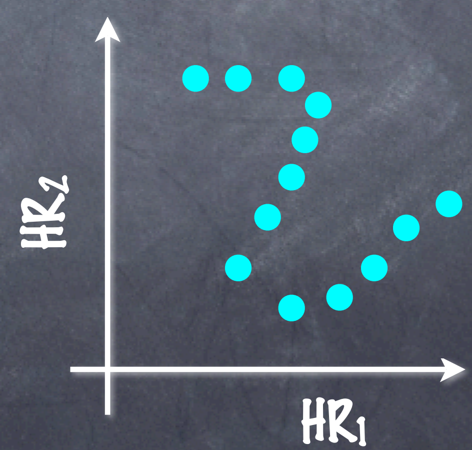
X-ray colors: CCD & HID



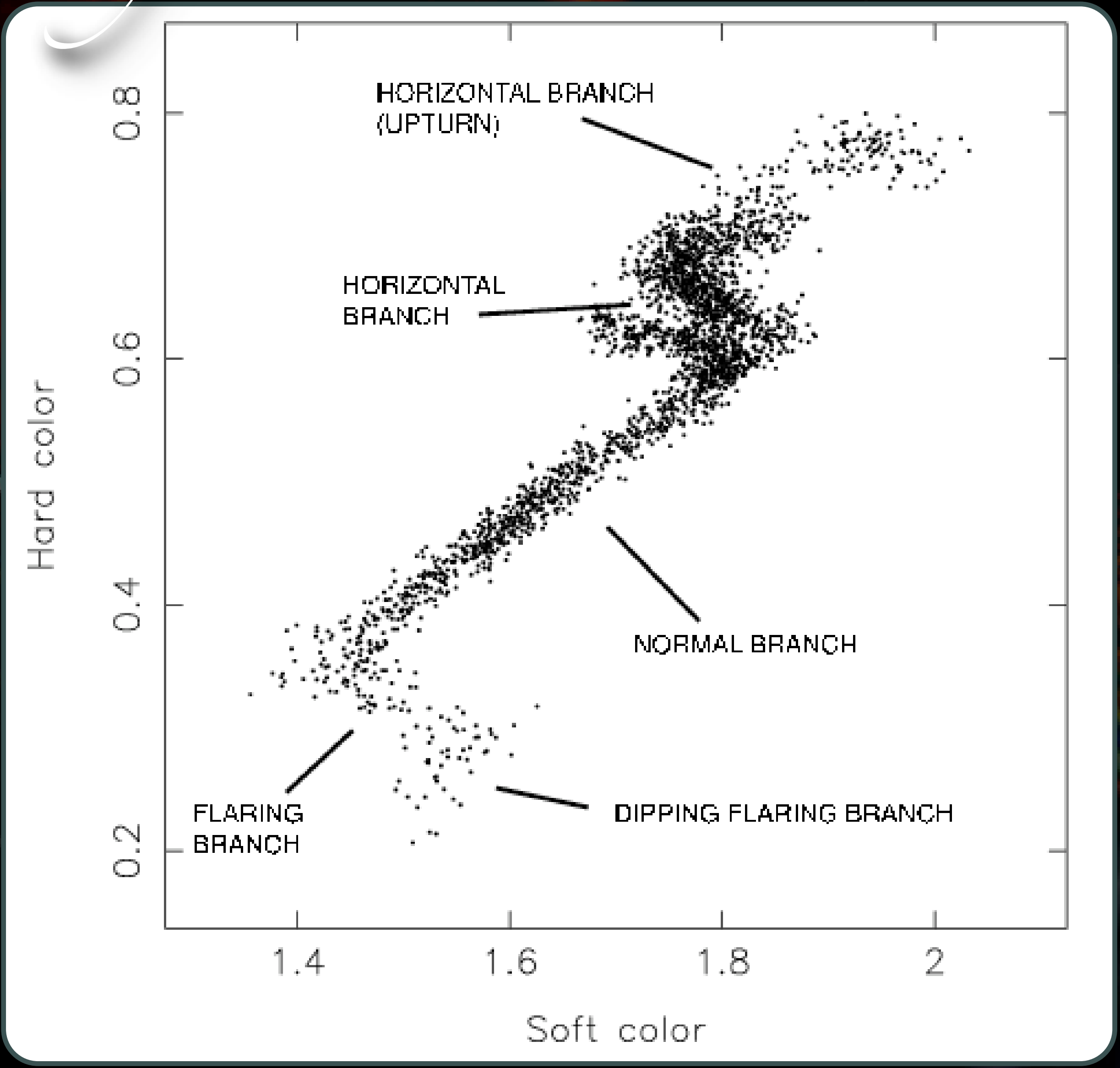
Colors: $HR_1 = B/A$
$HR_2 = C/A$

Rate: $R = A+B+C$





X-ray colors: CCD & HID

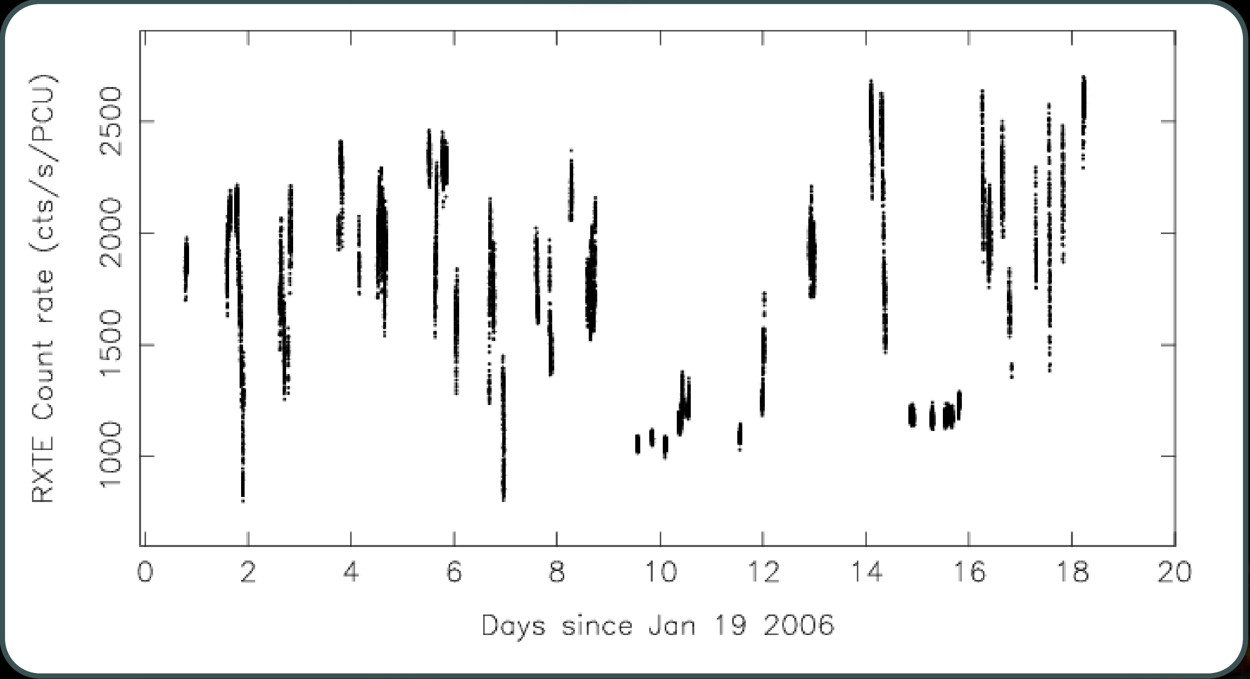


Why?

- Model independent
- Sensitive to small changes

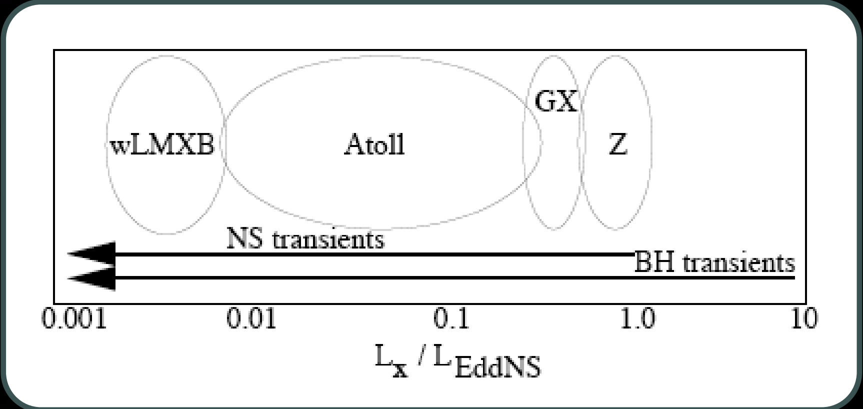
- Instrument dependent
- Need models

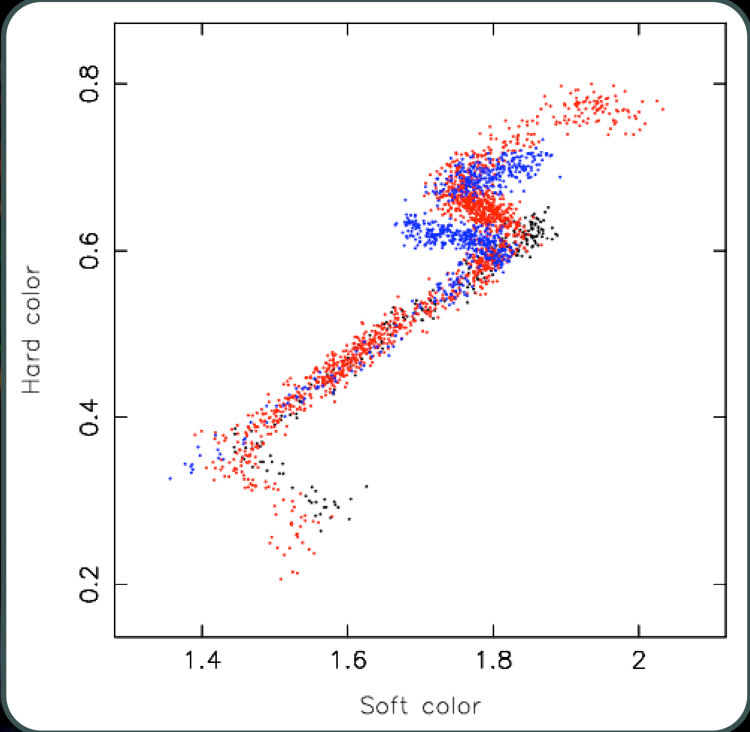
A new Z in town



XTE J1701-462

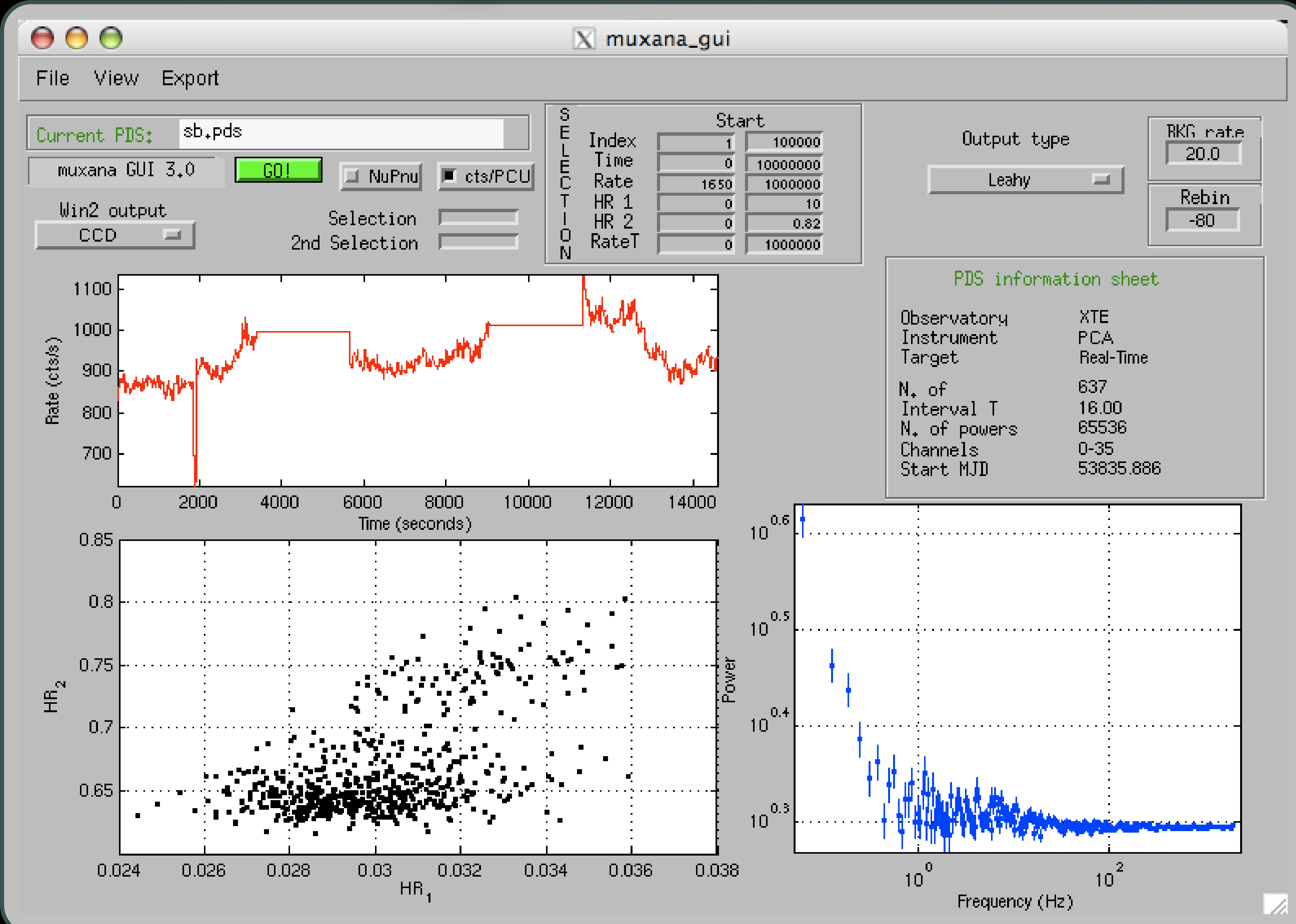
- January 2006
- Transient Z source
- A Rosetta stone?
- Already spanned Z-GX
- Waiting for quiescence..





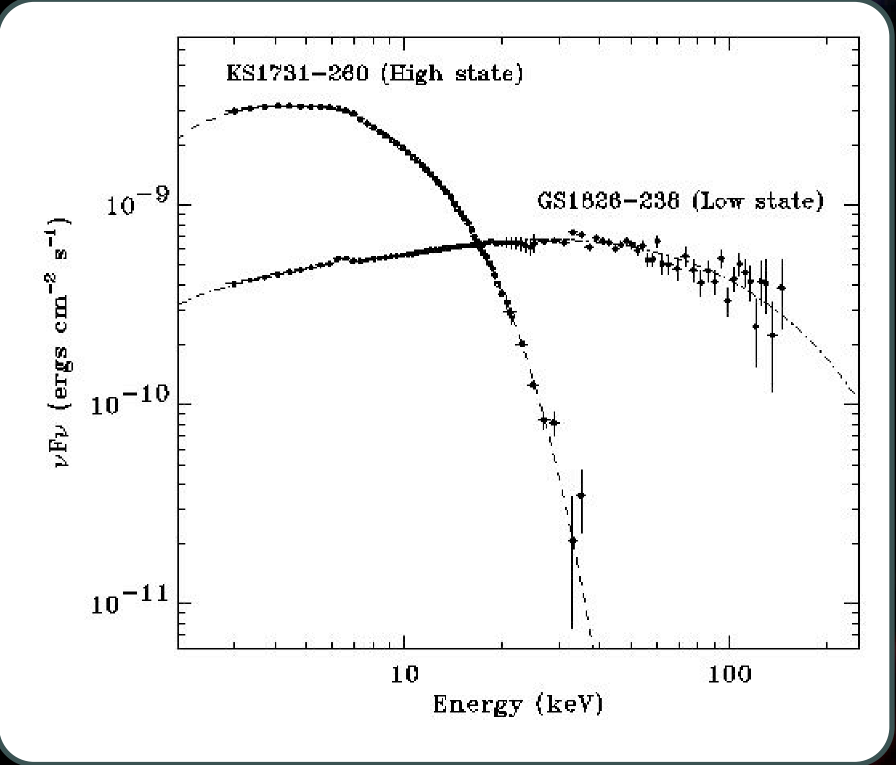
A new Z in town

Last night

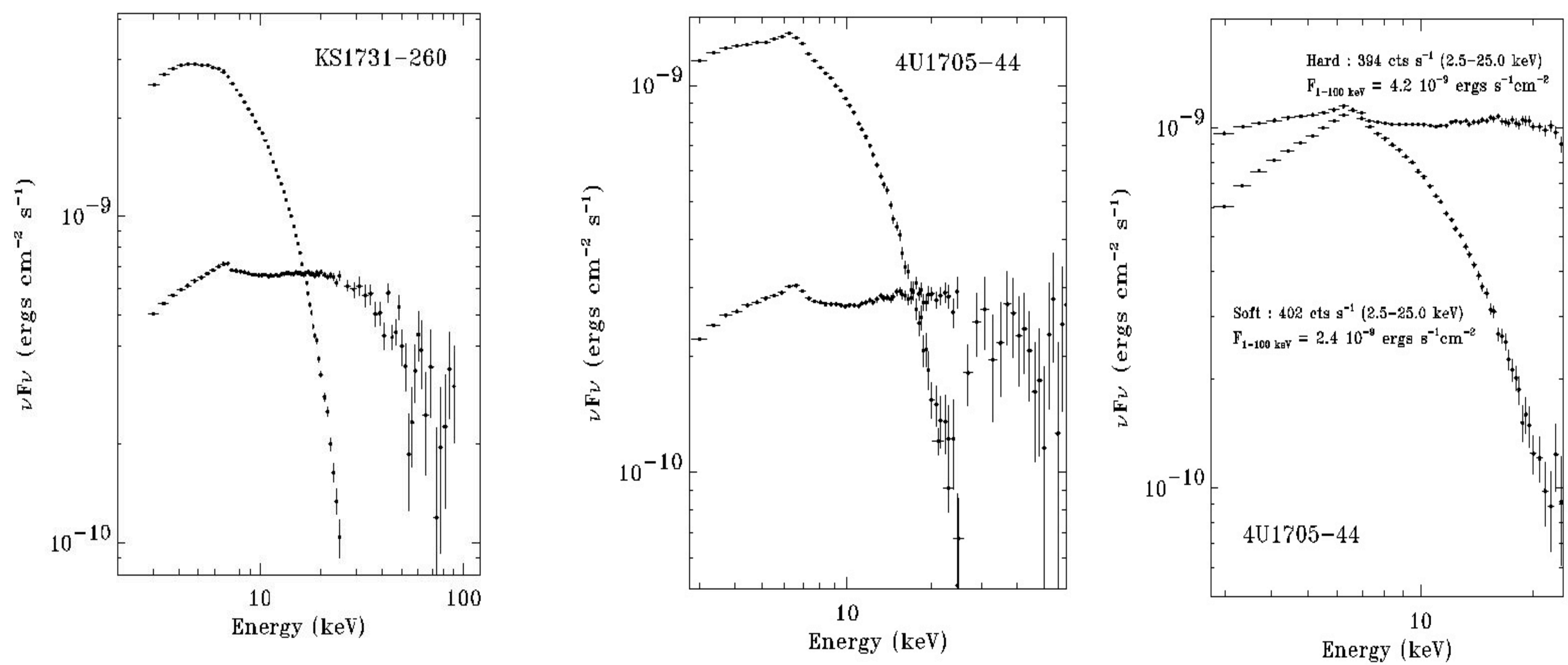


Energy Spectra: Atoll sources

- Soft component (few keV: blackbody or disk-BB
- Power law with exponential cutoff (5-20 keV): (thermal Comptonization)
- Soft and Hard states: in the hard state the cutoff shifts to higher energies (up to > 200 keV)
- Iron emission (fluorescence) line @6.4 keV
- Evidence for a Compton reflection component



Atoll sources: transitions



Barret et al. (2001)

- Usually: hard state (island)- lower flux (but see 4U 1705-44)
- At extreme island: low-luminosity bursters
- Similar to black-hole LS systems (lecture II)

Energy Spectra: Z sources

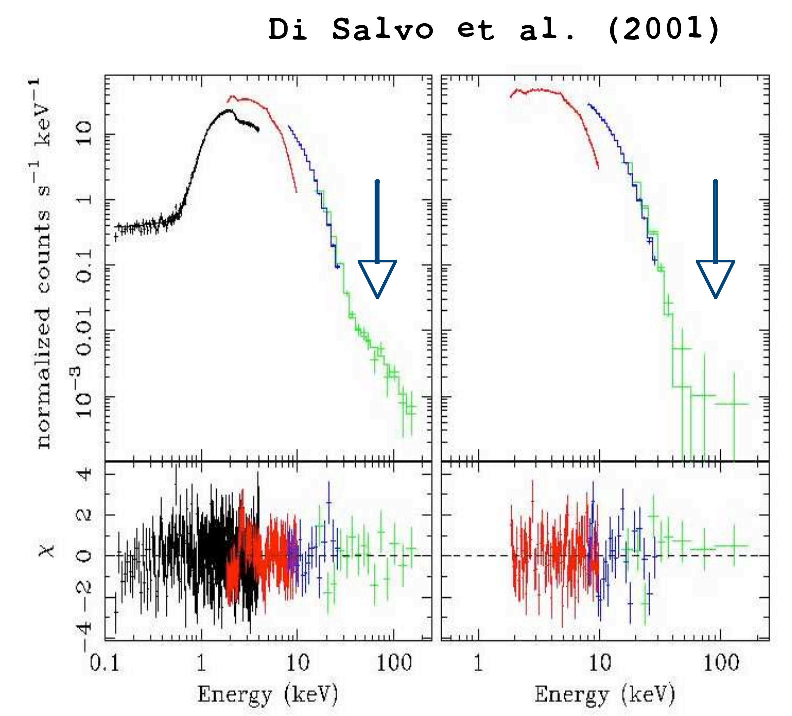
- Soft spectra, with cutoffs below 10 keV (many photons, Compton cooling)
- Two components (at least):

- Eastern model (Mitsuda et al. 1984):
  disk-blackbody + blackbody spectra
  (disk emission with $kT=aR^{-3/4}$ plus NS surface (Comptonized emission)

- Western model (White et al. 1986):
  blackbody + Comptonized blackbody spectra
  (NS or disk emission plus disk emission modified by Comptonization in a hotter region

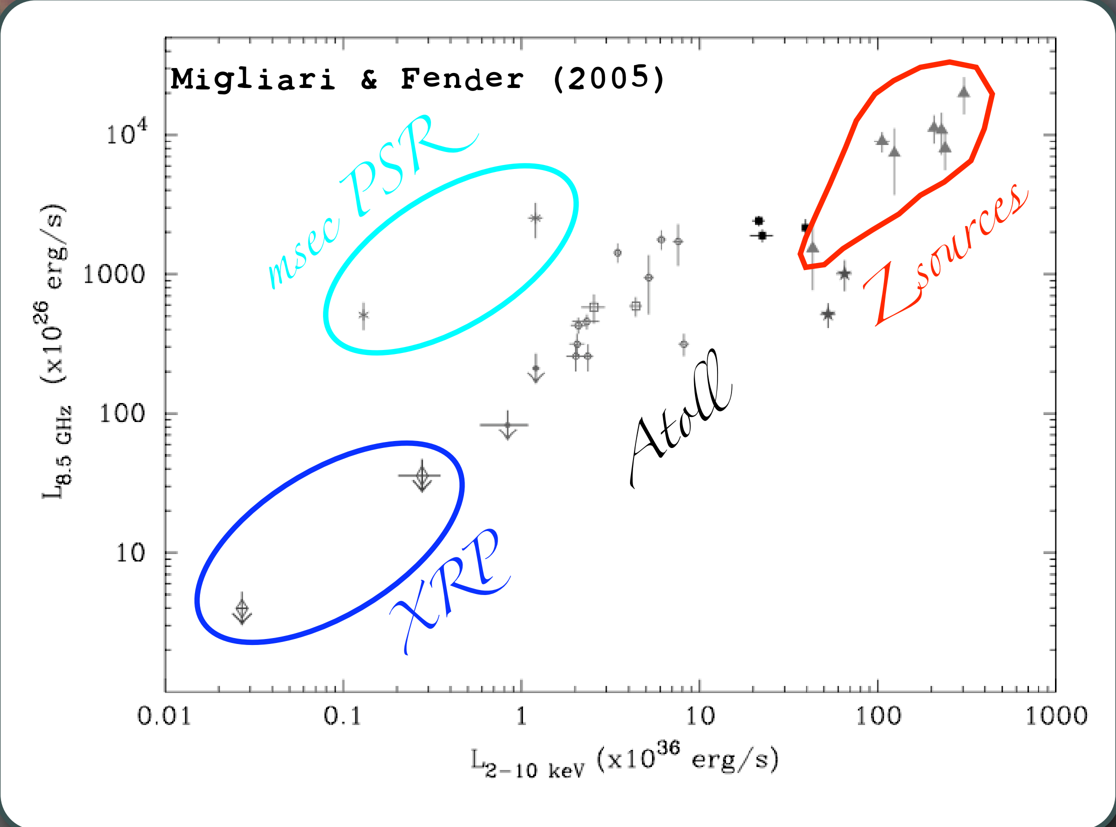
Z sources: hard tails

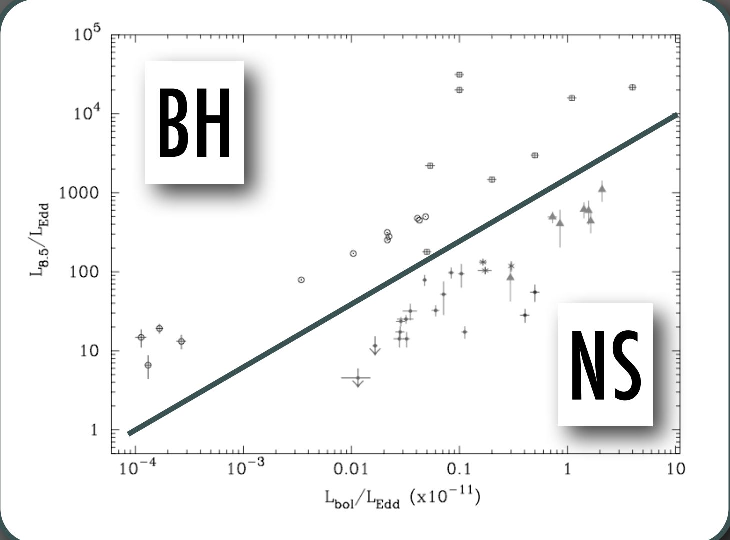
- RXTE+BSAX: additional hard components
- Index 2-3, up to 10% total flux
- Observed now in several systems
- Strongest on HB (low accretion rate)
- Sco X-1 and GX 349+2 are exceptions
- Radio flux also maximum in HB



NS binaries: radio emission

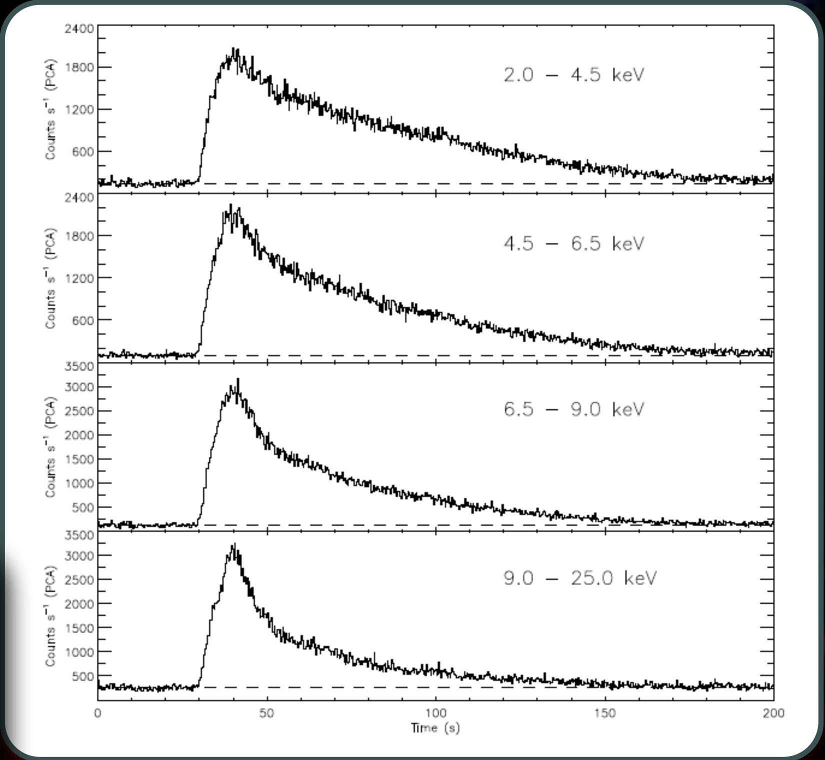
- Z sources: radio emission depends on Z position. All 6 detected.
- Atoll sources: only a few detected (30 times fainter)
- msec PSR: two detected (transient corresponding to outburst)

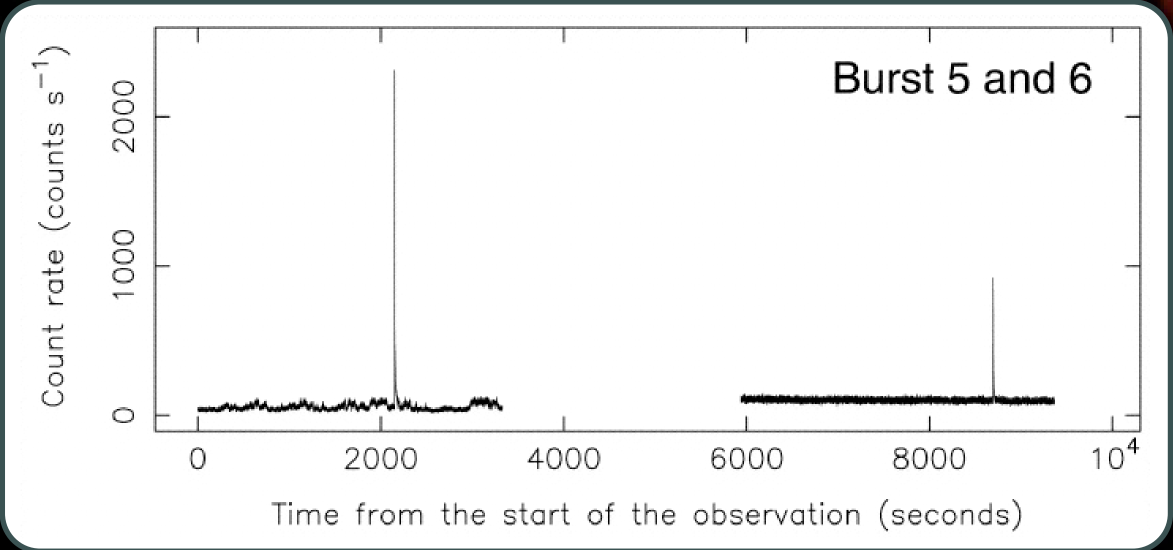




NS binaries: X-ray bursts

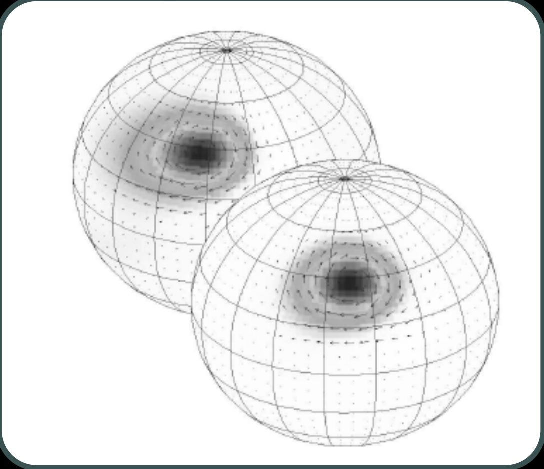
- Type II bursts: accretion-instability related
- Type I bursts: thermonuclear reactions on NS
  - Usually a few dozen seconds
  - Superbursts lasting hours

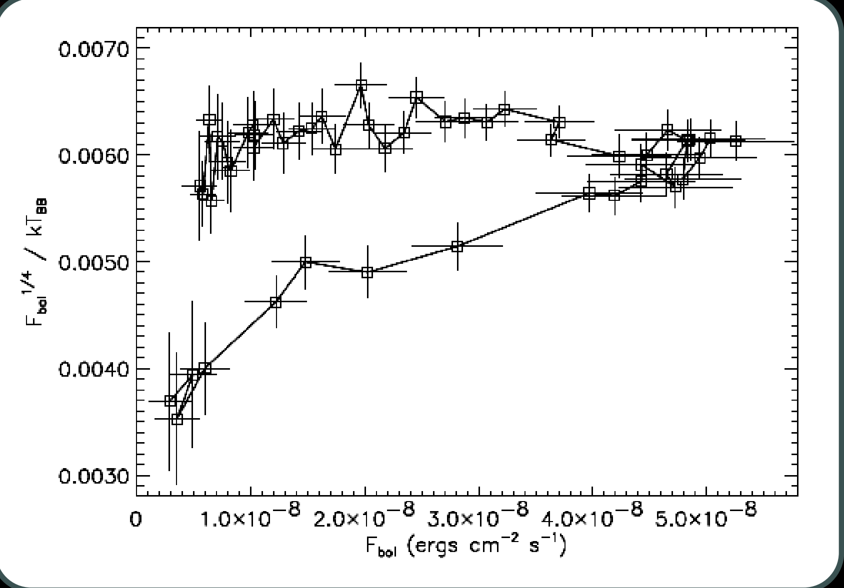




Type-I bursts in a nutshell

- Rise times shorter than decay
- Usually smooth
- Shorter at higher energies (cooling)
- Blackbody spectra: 10km radius [standard candles?]
- Bright bursts can reach L_{Edd}: photospheric expansion
- A lot of interesting physics
- ~~Burst oscillations~~ (tomorrow)

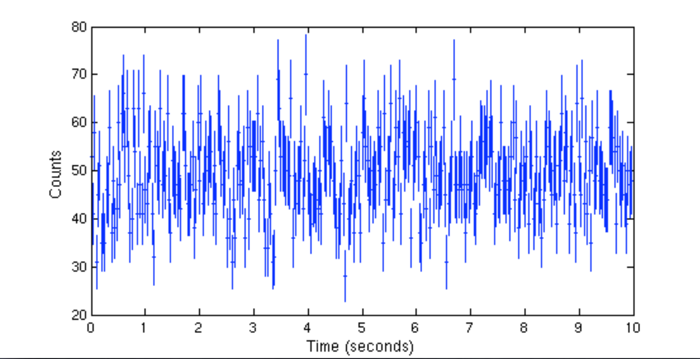




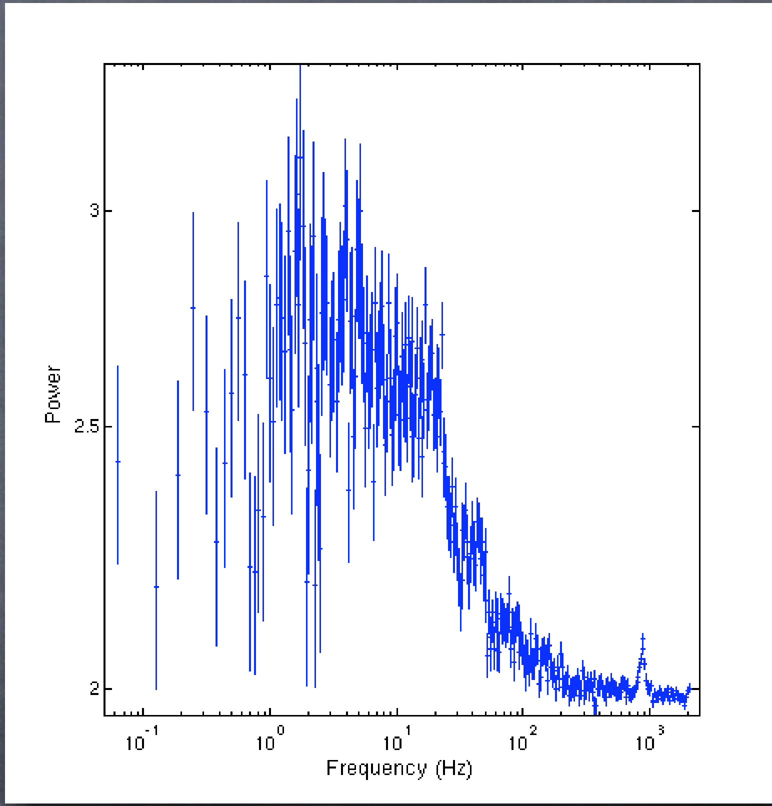
Strohmayer et al. (1997)

NS LMXB: timing

Light curve



Power Spectrum

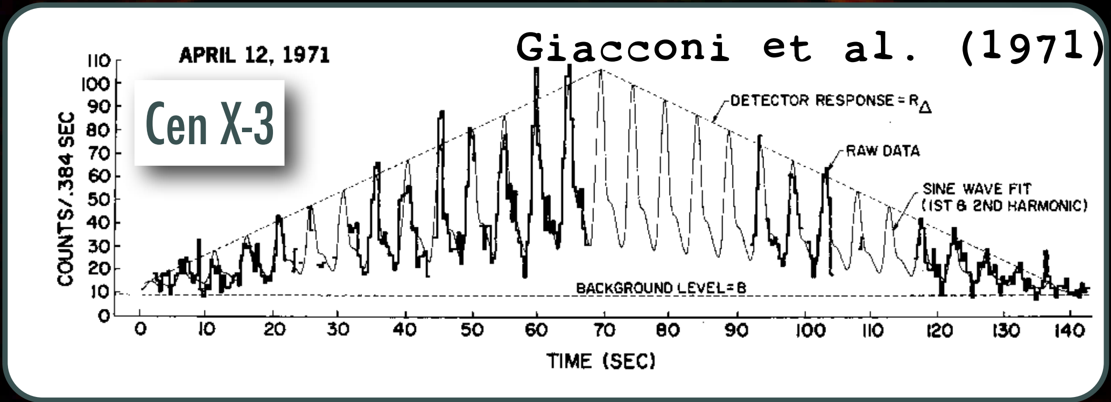


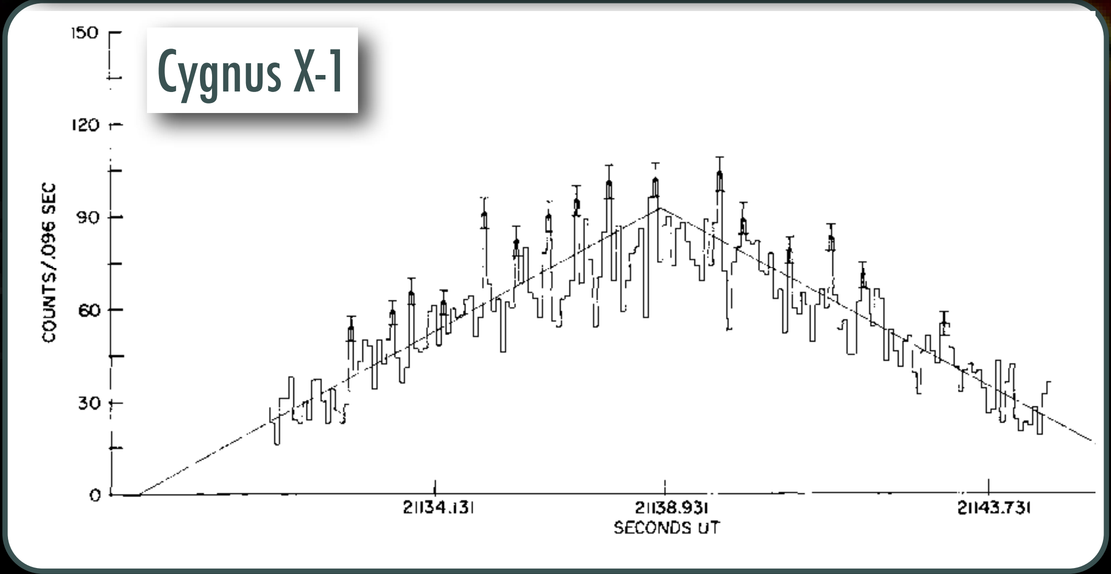
$$P_J = \frac{2}{N_\gamma} |a_j|^2$$

a_j : Fourier coefficients

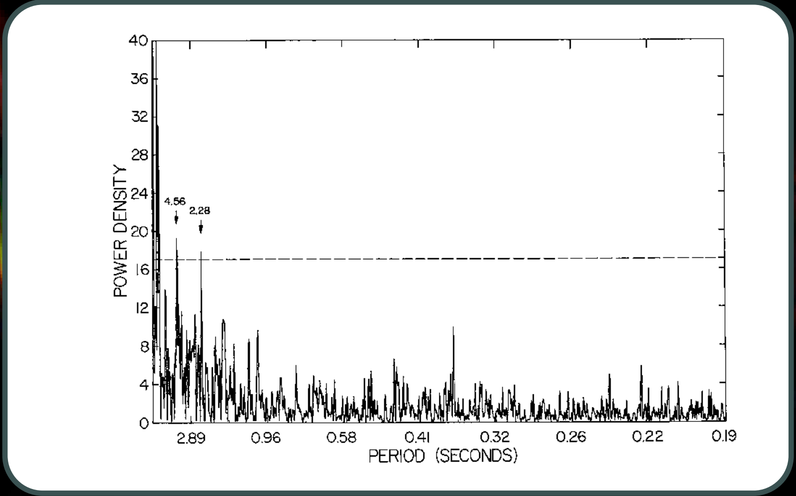
Aperiodic variability

Early X-ray timing





Some sources showed more than one period



Early X-ray timing

THE ASTROPHYSICAL JOURNAL, 172:L13–L16, 1972 February 15

DYNAMIC SPECTRUM ANALYSIS OF CYGNUS X-1

M. ODA, M. WADA,* M. MATSUOKA, S. MIYAMOTO,
N. MURANAKA, AND Y. OGAWARA
Institute of Space and Aeronautical Science, University of Tokyo, Tokyo
Received 1971 December 16

ABSTRACT

The oscillatory structure of the counting-rate data trains of Cyg X-1 obtained by the AS&E and the M.I.T. group was studied. Instead of applying the Cooley-Tukey fast Fourier-transform algorithm to the entire data, we obtained the dynamic spectrum by fitting the wave with time sections of the data trains. Also, the Hissagram, which is a quantitative exhibition of the sonagram, was produced for the same train. It was concluded that the oscillation lasts typically for several seconds and its frequency drifts within a few seconds repeatedly.

THE ASTROPHYSICAL JOURNAL, 174:L35–L41, 1972 May 15

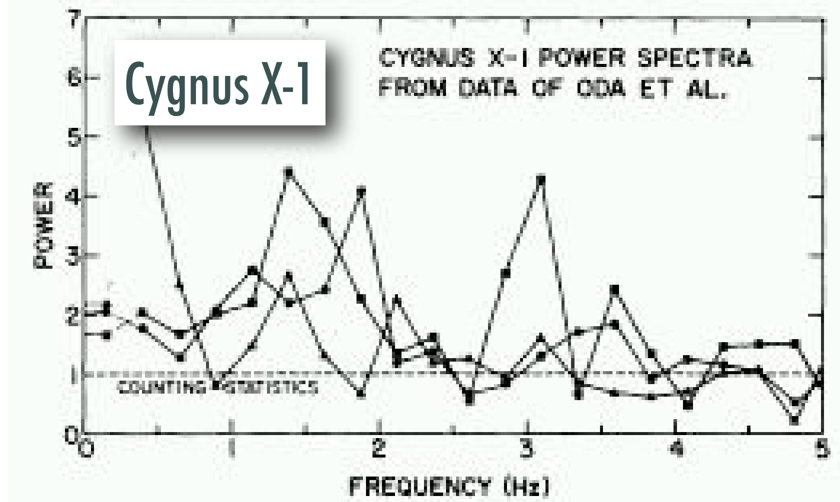
SHOT-NOISE CHARACTER OF CYGNUS X-1 PULSATIONS*

N. JAMES TERRELL, JR.
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1972 February 22

ABSTRACT

The pulsating X-ray source Cyg X-1 has been reported as having various conflicting or changing periodicities, or as being nonperiodic. The reported data have been reanalyzed in an effort to clarify this situation, and are found to be indistinguishable from shot noise due to short overlapping outbursts of X-ray emission, with no true periodicity. Computer-generated shot-noise data have the same appearance and lead to similar power spectra. The observational data are consistent with random pulses which have an effective pulse length of 0.3 ± 0.1 s and occur at varying rates of the order of several hundred per second. The pulse length indicates a maximum source size of ~ 0.8 light-seconds. It is suggested that some other fluctuating X-ray sources, such as Sco X-1 and Cir X-1, may also have such a shot-noise character.

Answer: no period present. Noise.



X-ray binaries II

Tomaso Belloni
(Osservatorio Astronomico di Brera)

Thierry Lombry

X-ray b

Tom

(Osservatorio Astronomico di Brera)

Thierry Lombry

- Part I
  - X-ray pulsars
  - Neutron star LMXB
- Part II
  - Neutron star LMXB
  - Black-hole binaries

NS, B field

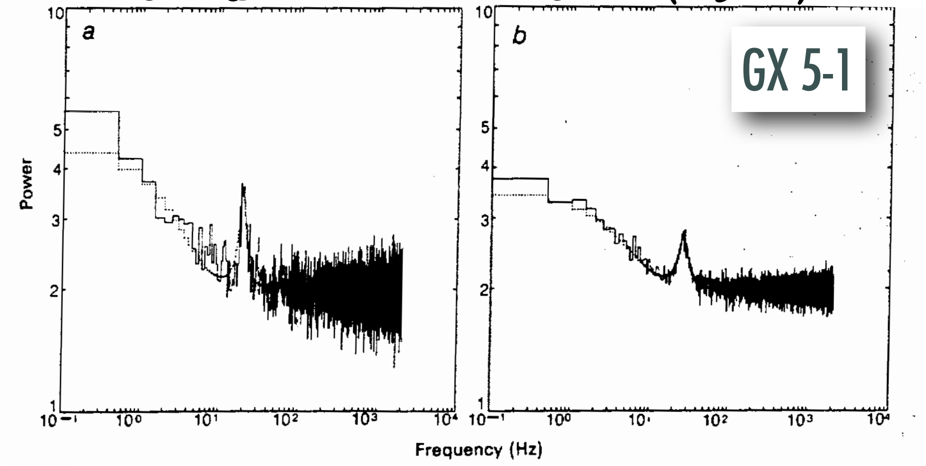
small R, GR

NS LMXB

Quasi-Periodic Oscillations

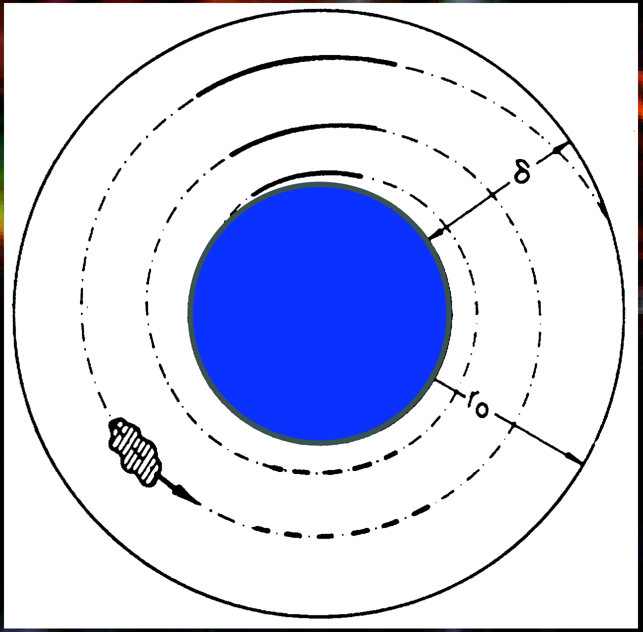
- GX 5-1 first source
- Broad and slow features
  - Not a pulsar
  - No keplerian time scale
- Correlated with count rate (flux?)
- State-dependent

van der Klis et al. (1985)



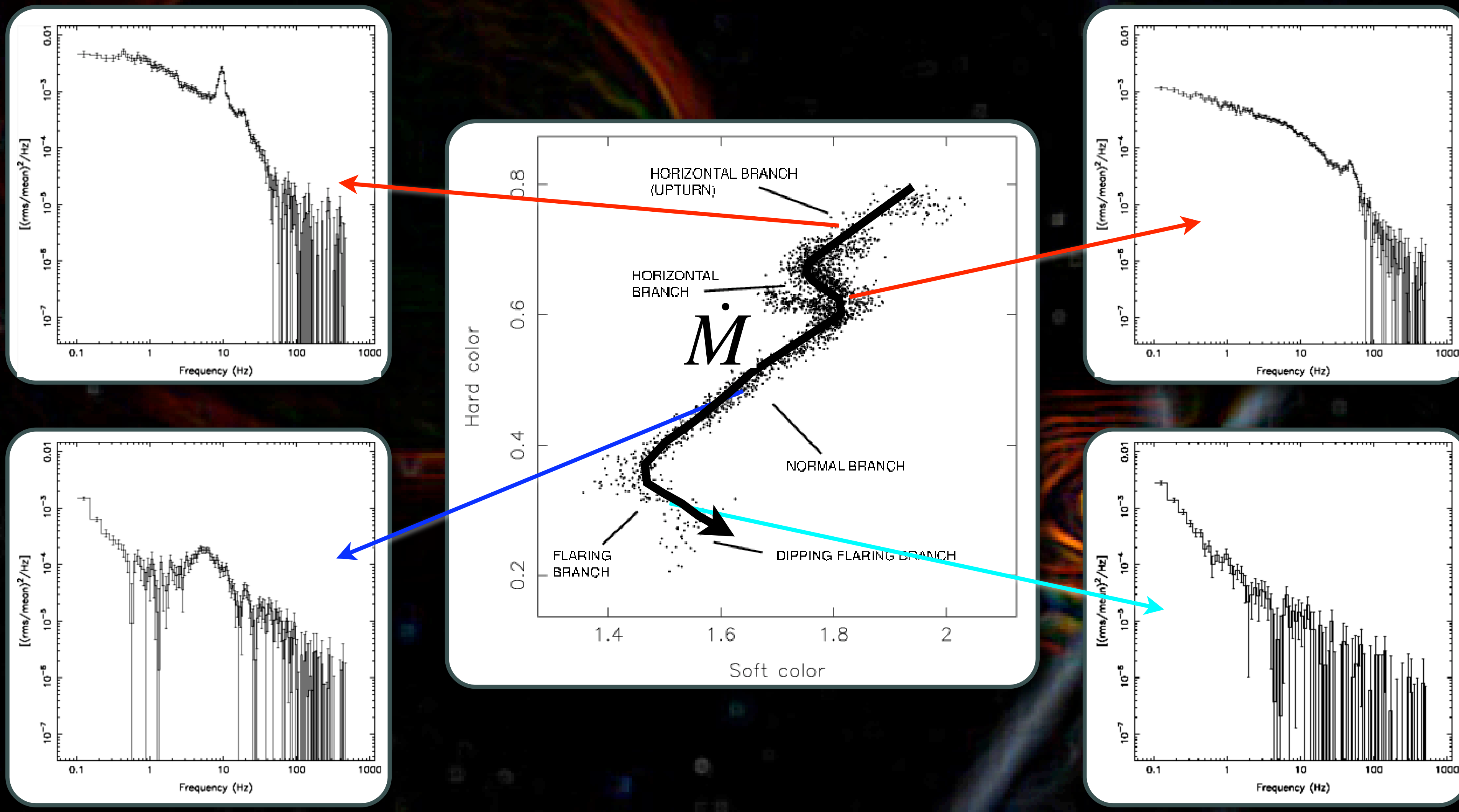
Beat frequency $\omega = \Omega_K(r_A) - \Omega_{spin}$

Flux related: $\omega \propto L_{37}^{3/7}$

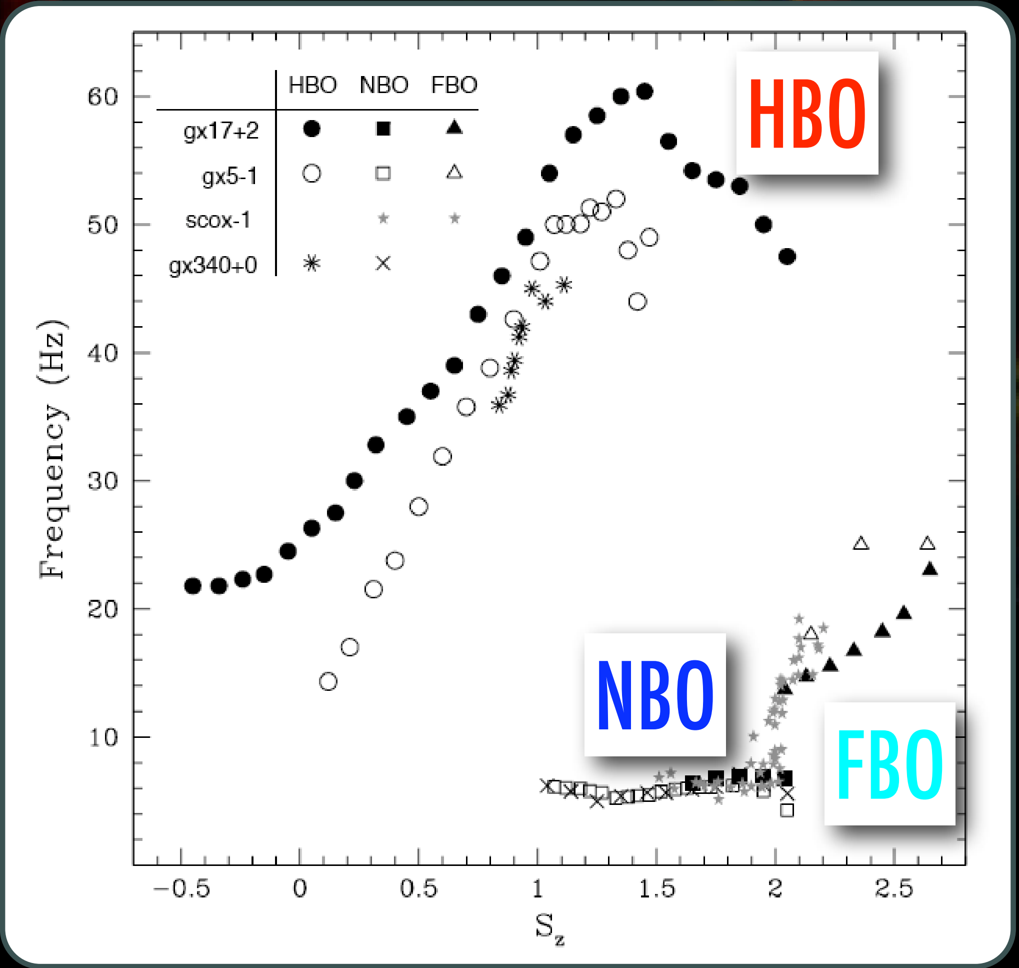


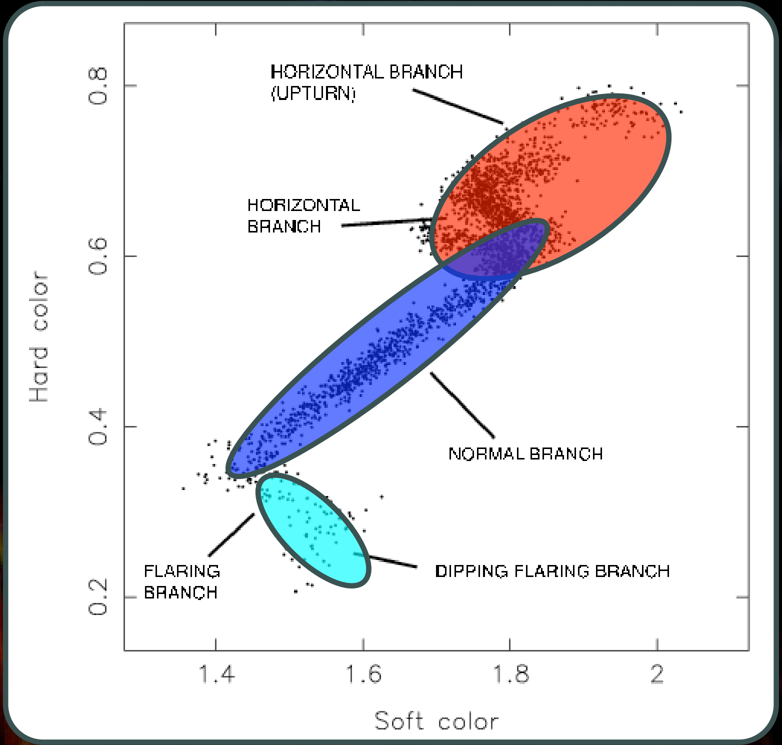
Alpar & Shaham 1985
Lamb et al. 1985

Quasi-Periodic Oscillations



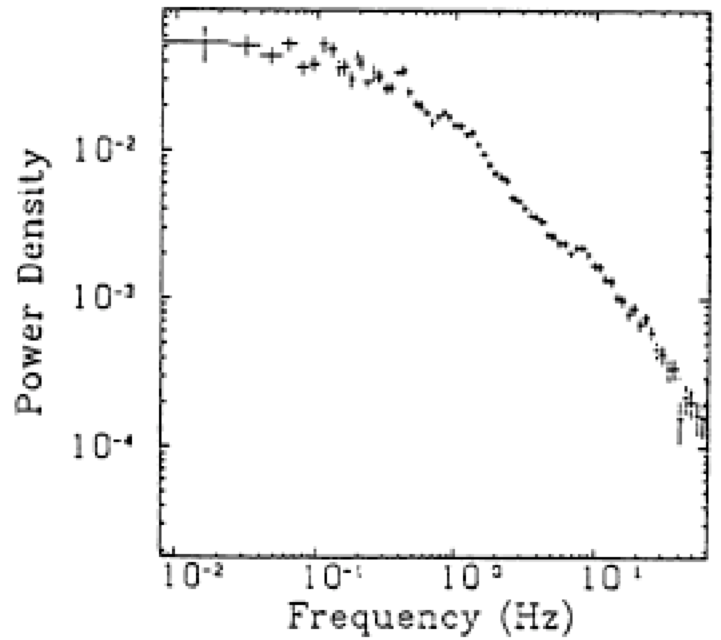
Three types of Z QPOs





Atoll QPOs & noise

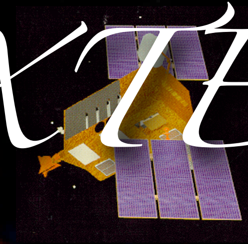
- At low flux: flat-top noise + LFQPO
- Same as low-L bursters

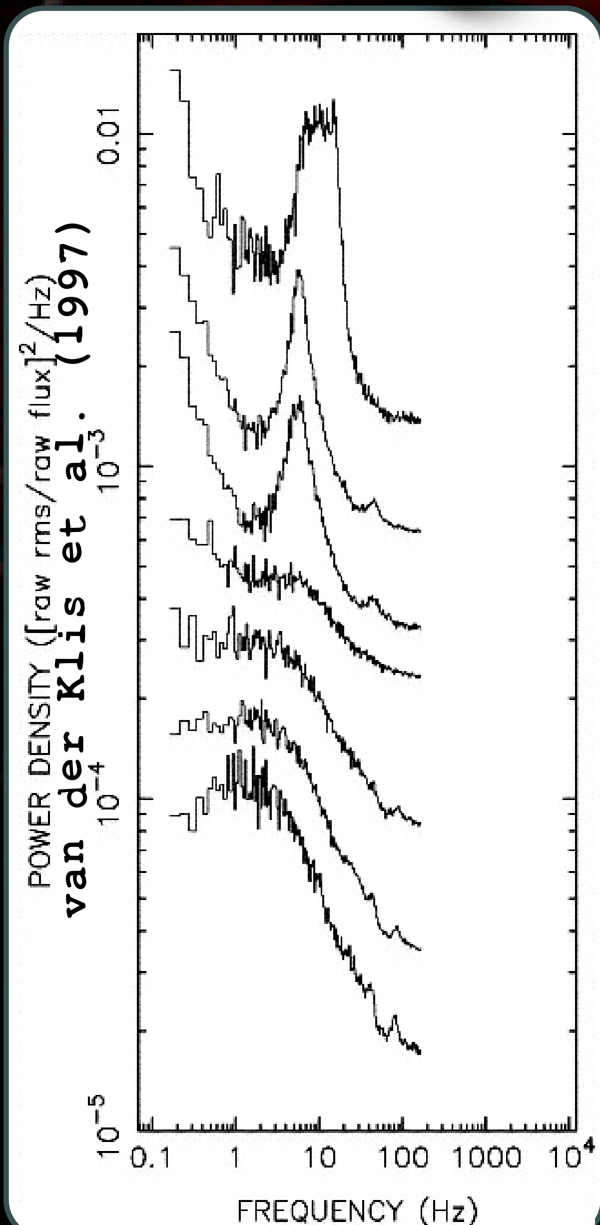


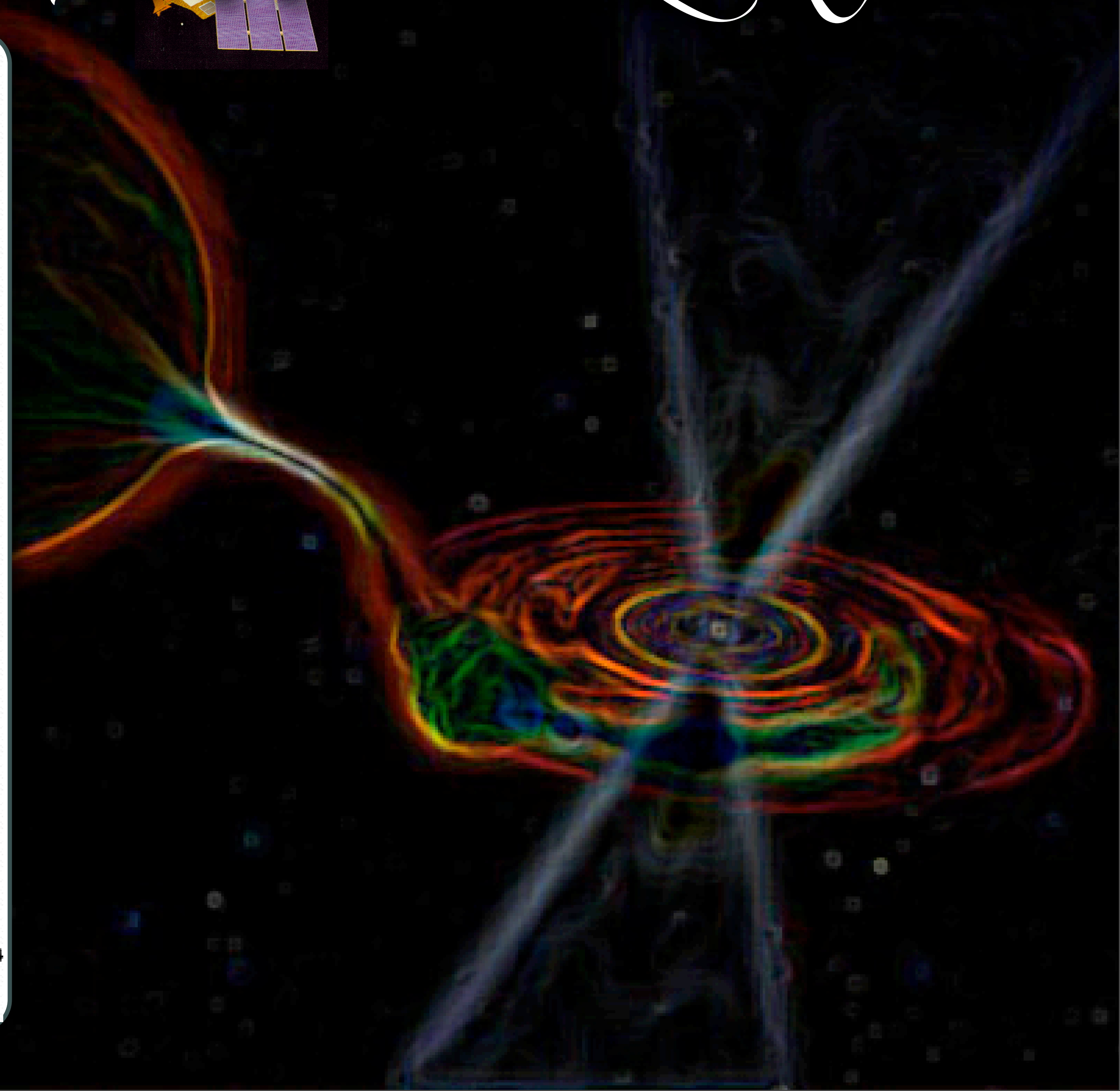
Inoue (1992)

Apologies for the phenomenology: we will need it later

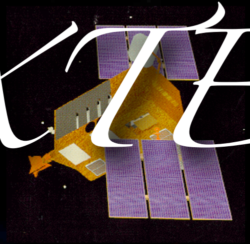
Enter RossiXTE: kHz QPO

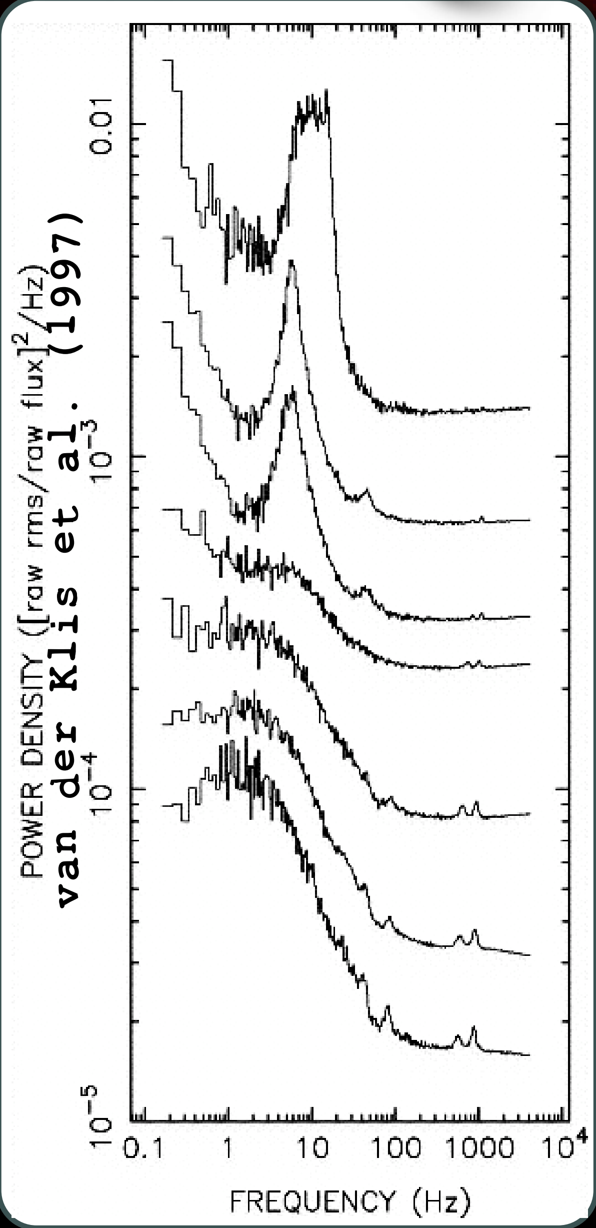




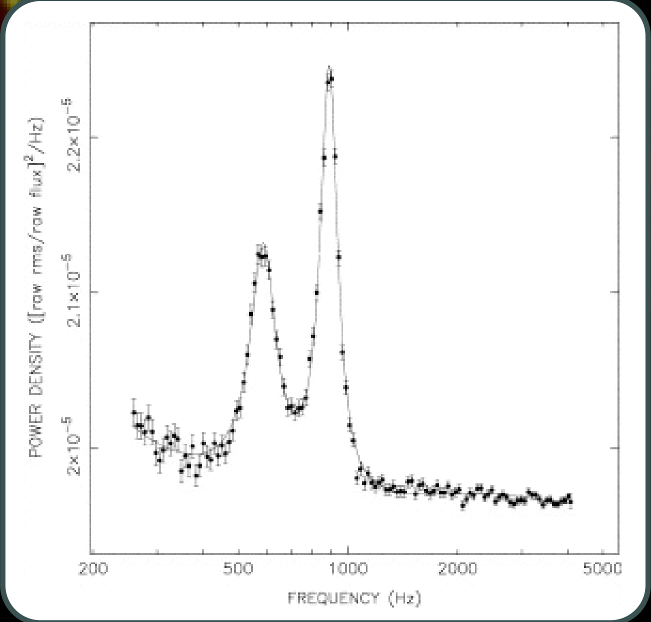


Enter RossiXTE: kHz QPO



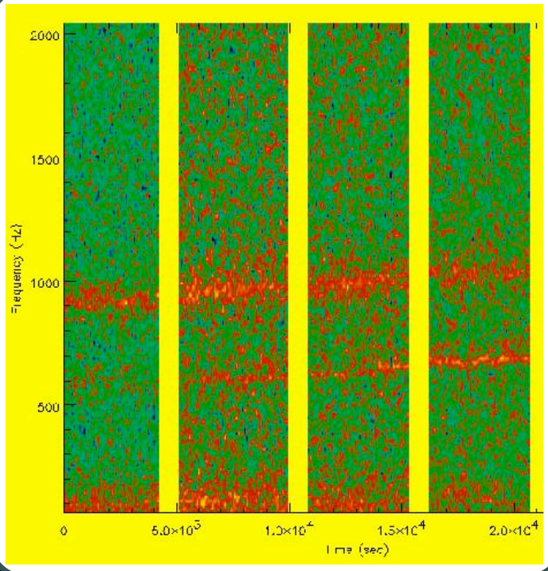


- Double peaks at high frequency
- Expected range for Keplerian
- Frequency changes
- Sco X-1 first, then other Z and atoll



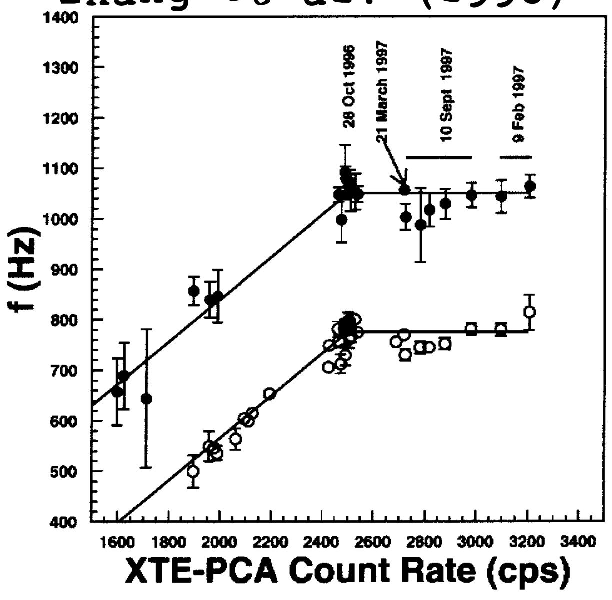
kHz QPO: basic properties

- Seen in nearly all Z and atoll sources
- Twin peaks move in 200-1200 Hz range
- Difference almost constant?
- At extreme frequencies, only one peak

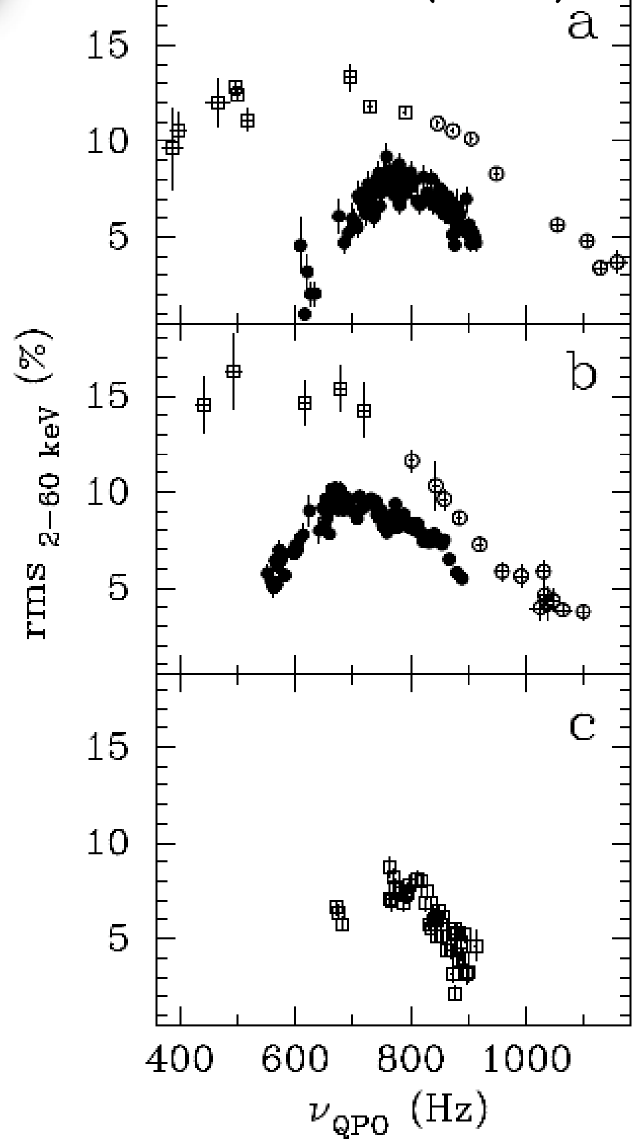


Strohmayer et al. (1996)

Zhang et al. (1998)



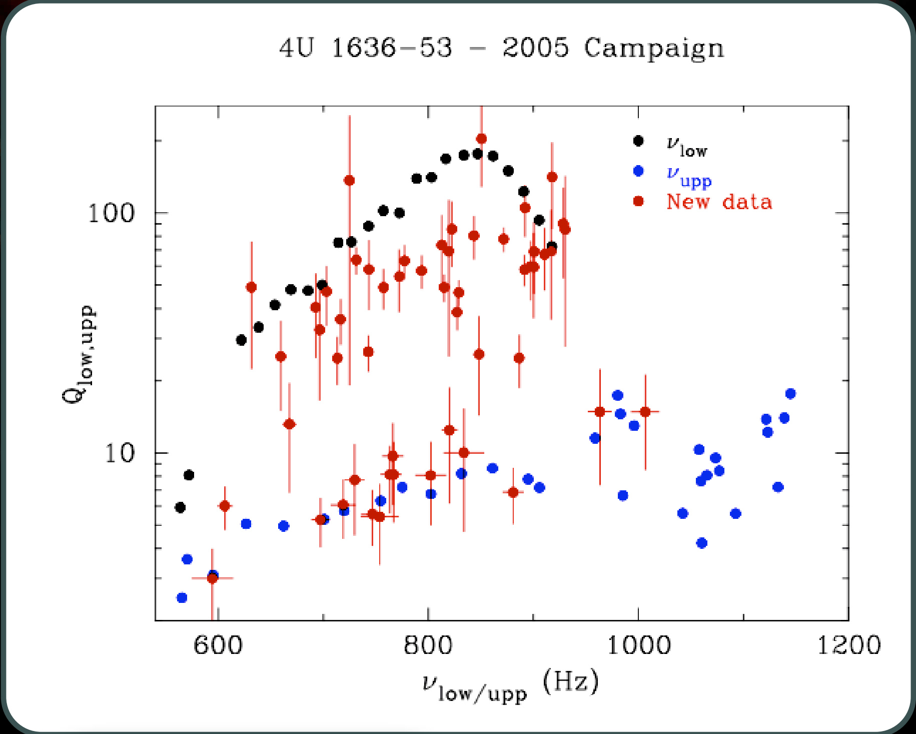
Méndez et al. (2001)



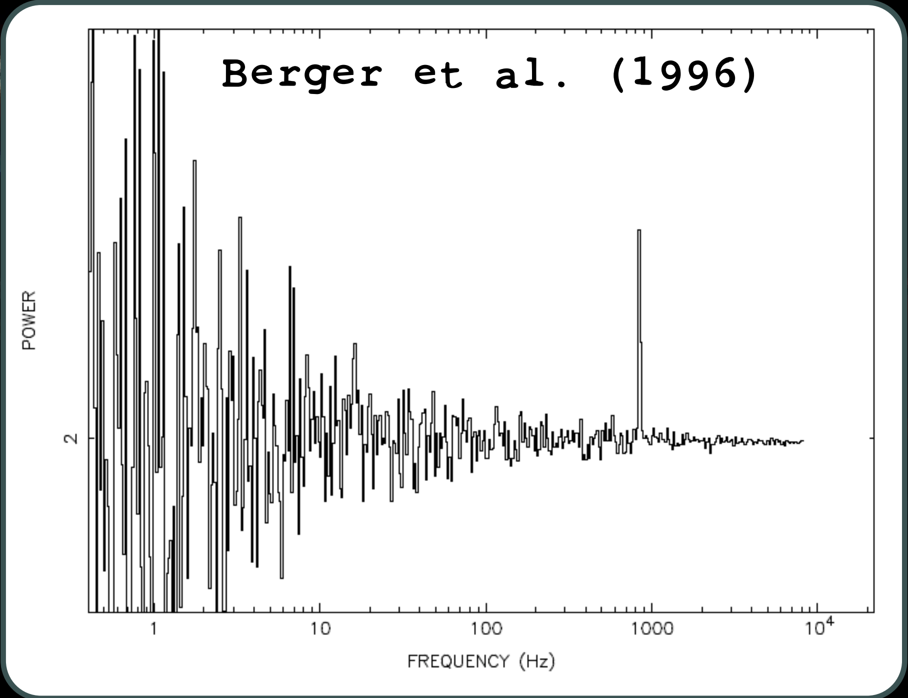
kHz QPO: basic properties

- Q factor can be as high as 200

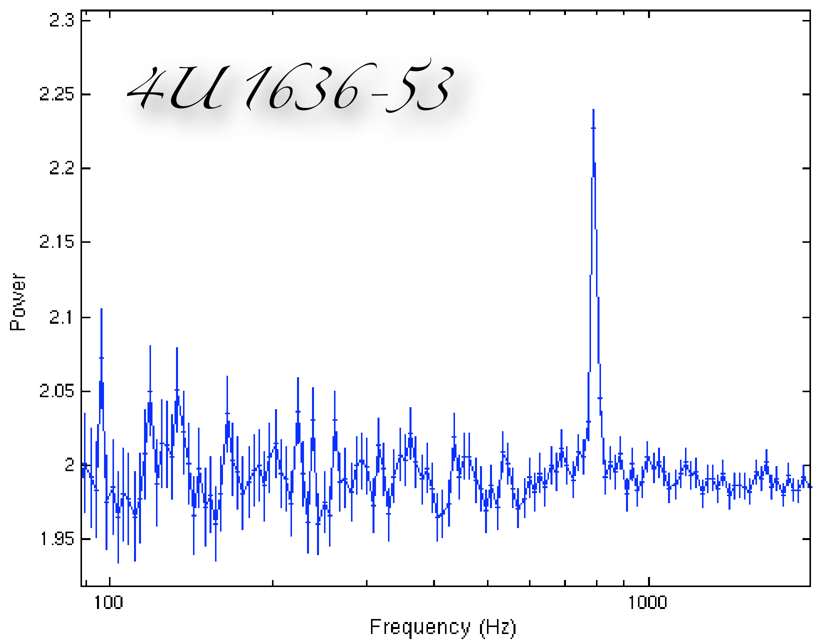
Quality factor $Q = \dfrac{\nu_0}{\Delta\nu}$

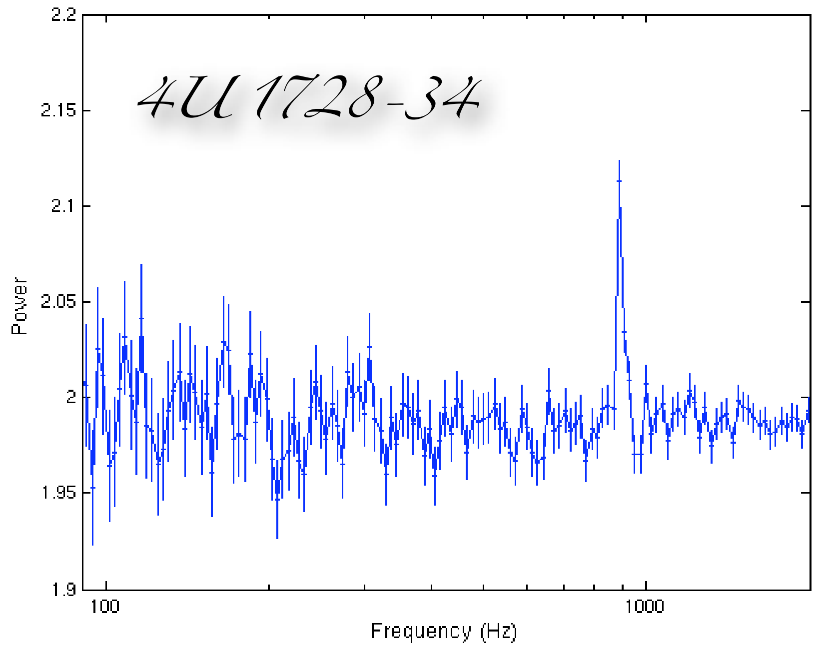


Méndez et al. (2006)



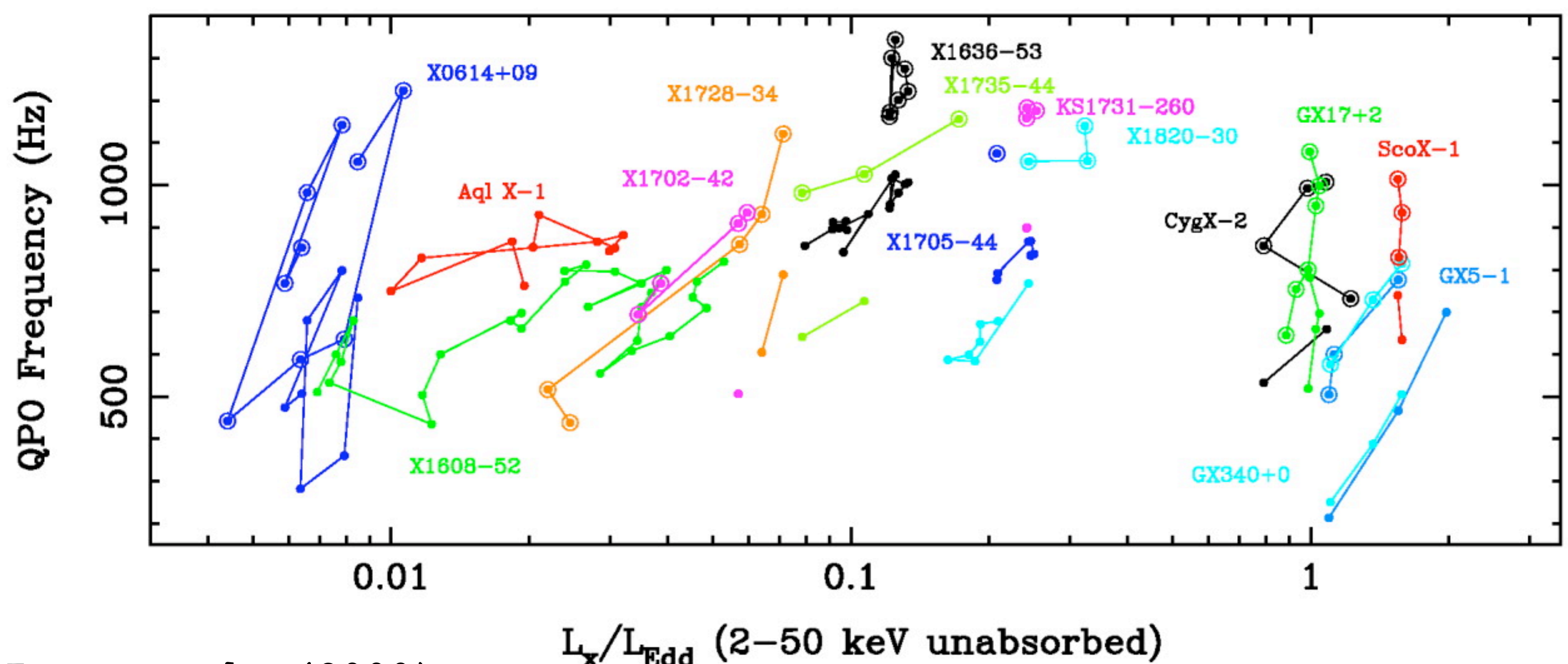
kHz QPO: Sunday edition





kHz QPO: basic properties

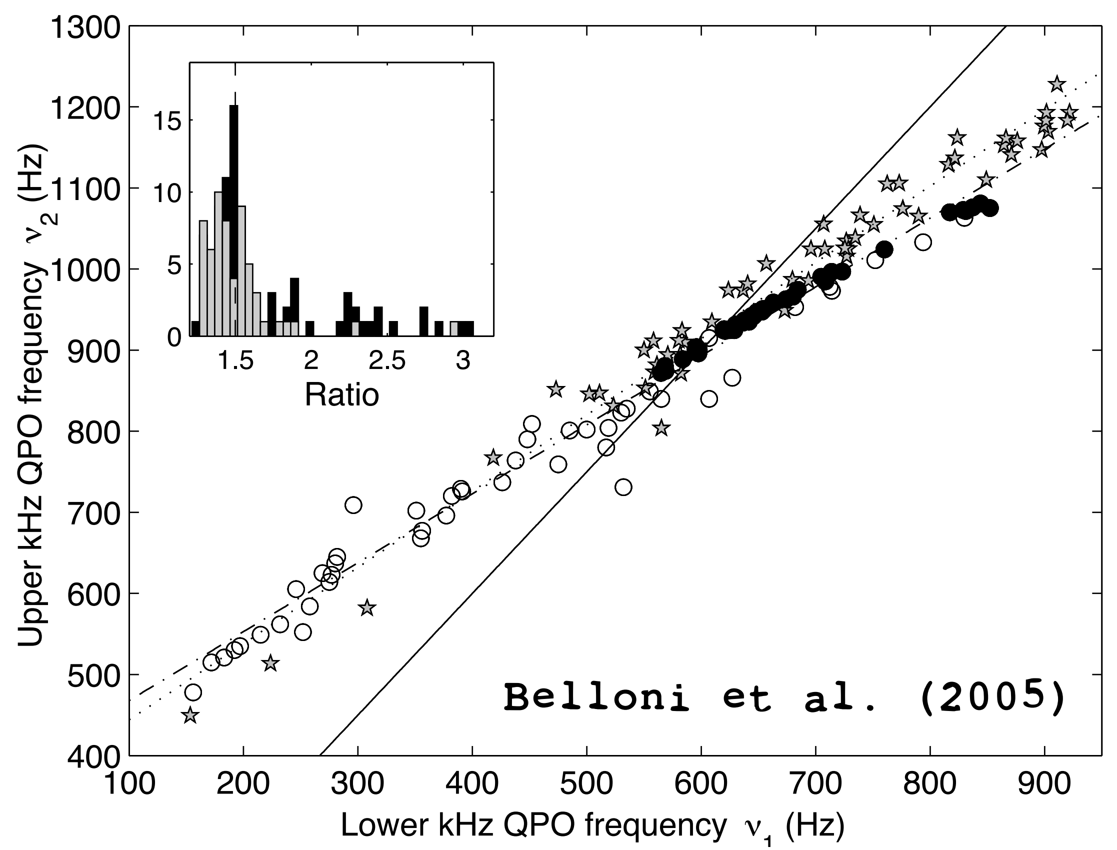
- Frequency shift on "parallel tracks"

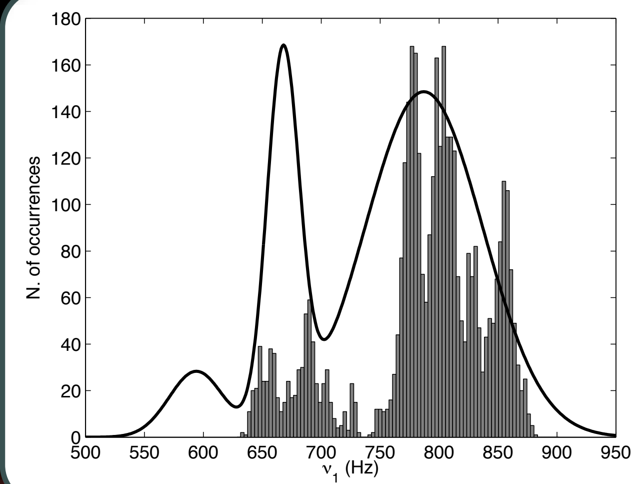


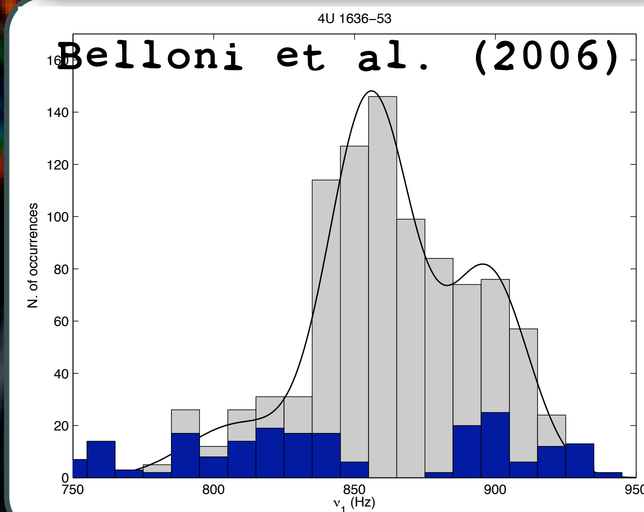
Ford et al. (2000)

kHz QPO: basic properties

- No preferred frequency or frequency ratio







kHz QPO: higher math

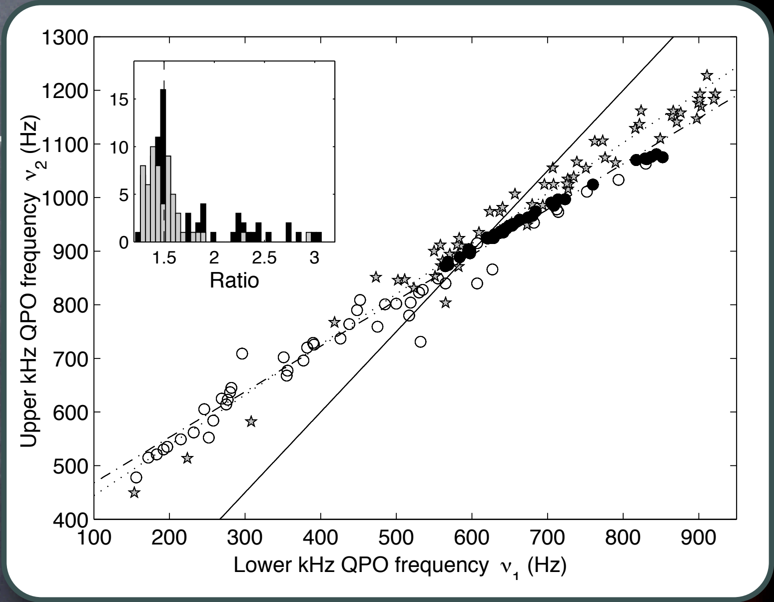
Basic equation:

$$y = ax + b$$

Derived equations:

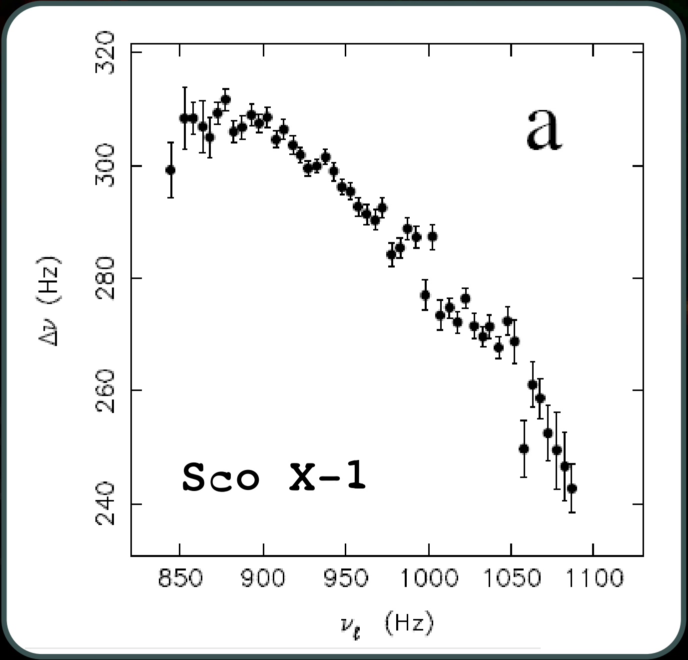
$$y/x = a + \frac{b}{x}$$

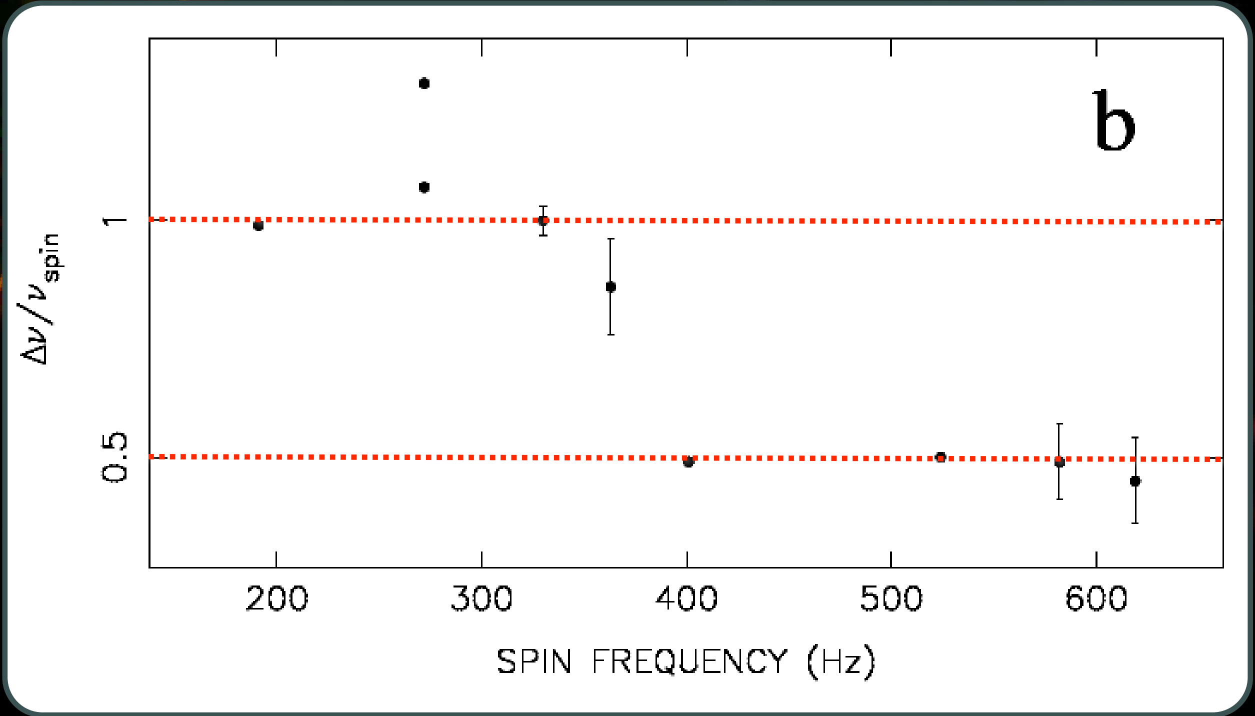
$$a = -\frac{b}{x} + \frac{y}{x}$$



kHz QPO: basic properties

- Frequency difference does vary
- Connected to the spin frequency of the NS



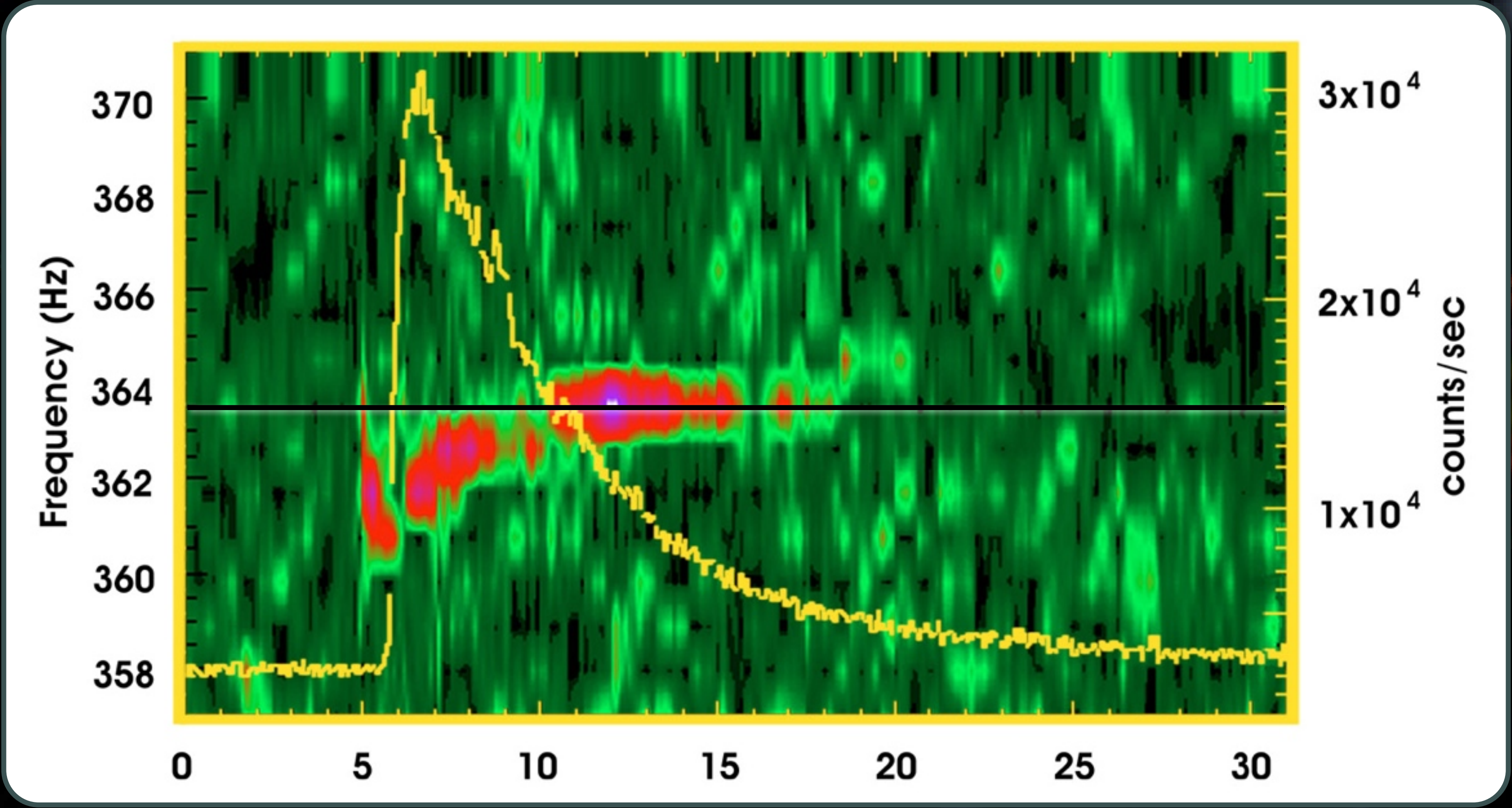


How do we know the spin frequency?

Burst oscillations: the spin?

- Coherent oscillations
- Give characteristic frequency

Hot spot burning on NS: complex

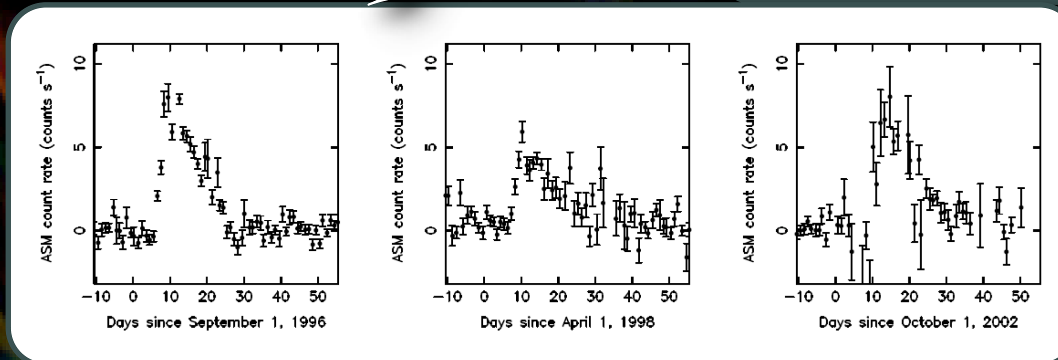


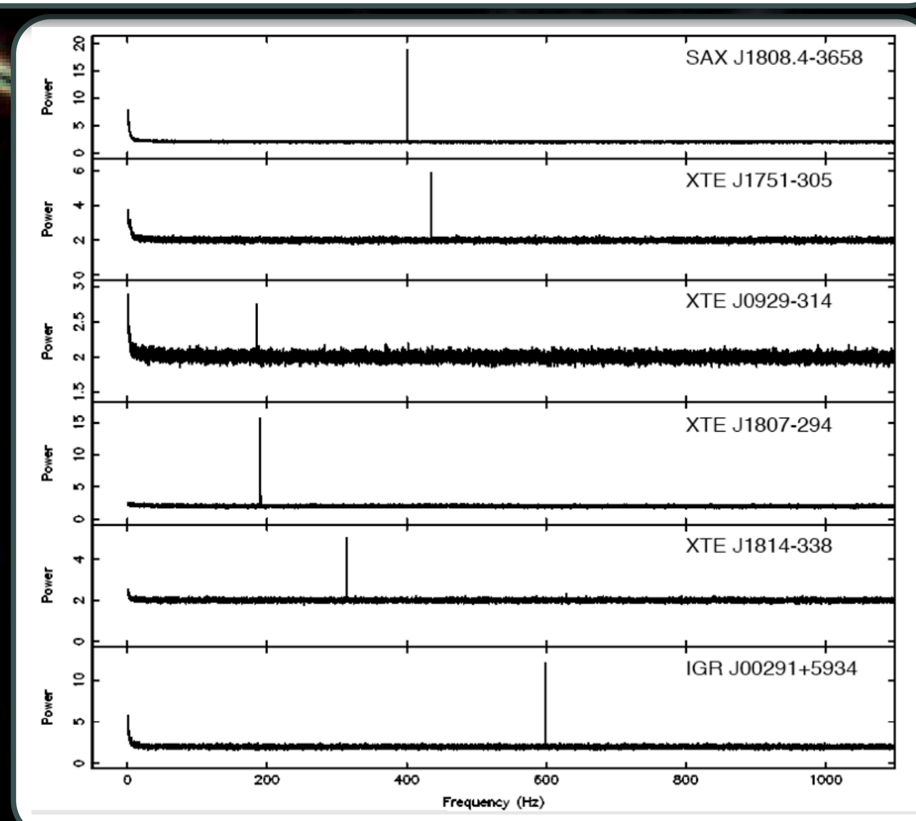
Accreting millisecond pulsars

- In 1999 first one found
- Seven known to date
- Faint transients
- 200-600 Hz pulsations

The missing link

Wijnands 2005

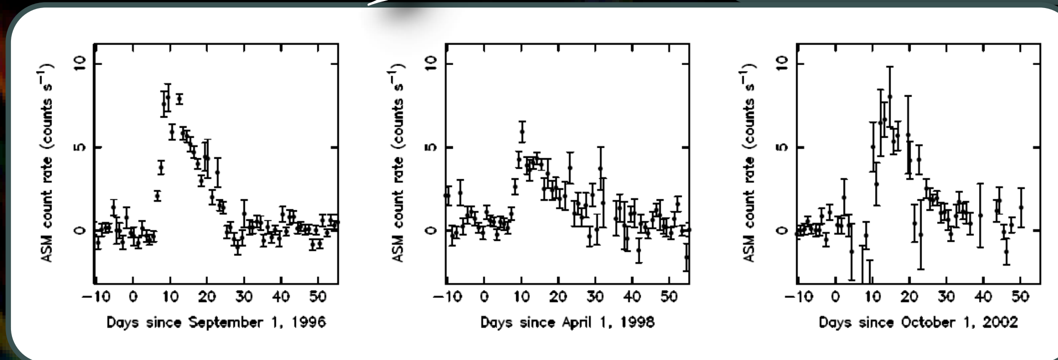


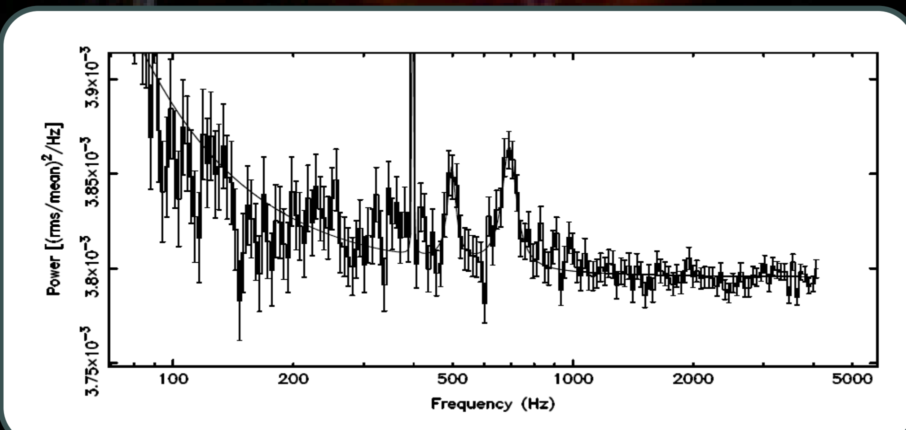


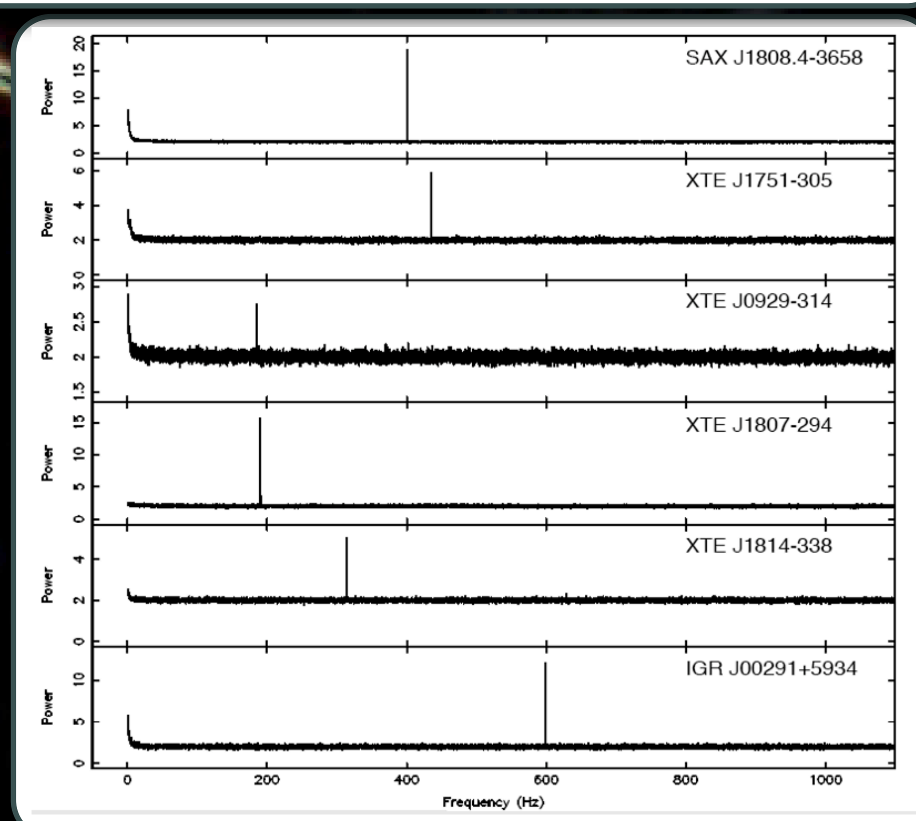
Accreting millisecond pulsars

Wijnands 2005

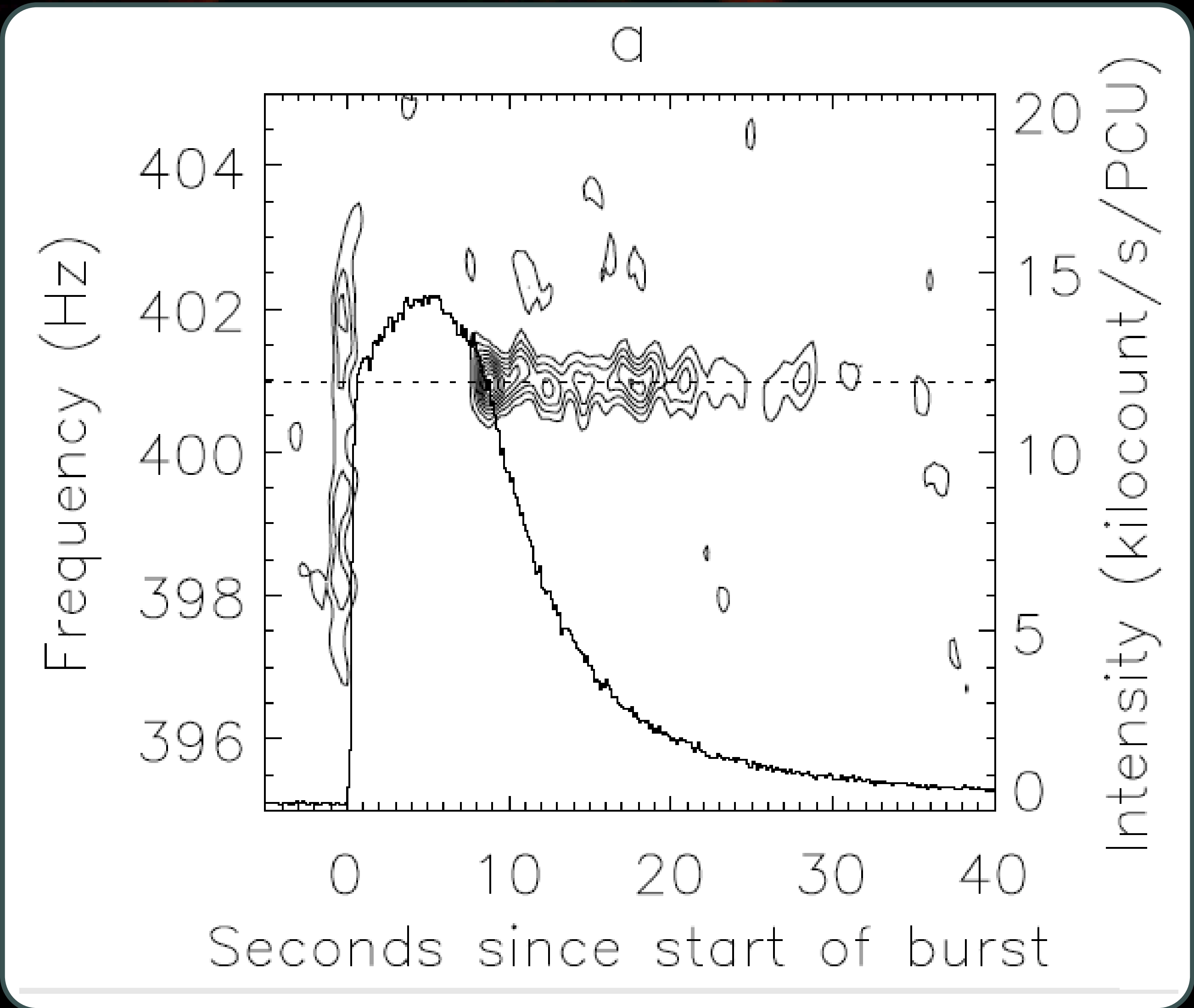
- In 1999 first one found
- Seven known to date
- Faint transients
- 200-600 Hz pulsations
- Show kHz QPO
- Δν as expected







Burst oscillations: the spin!

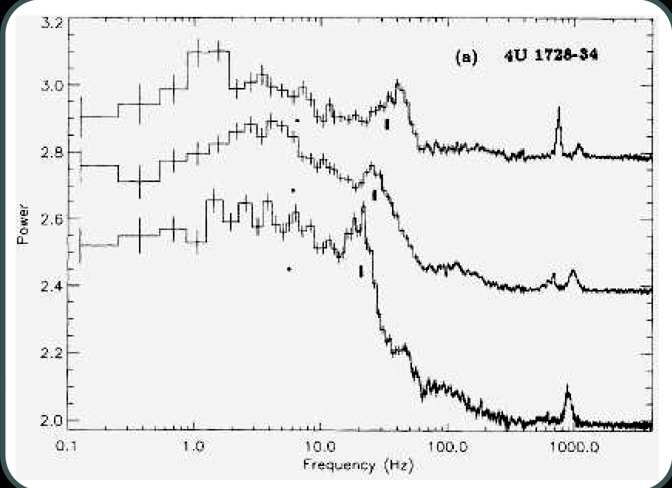


Chakrabarty et al. 2003

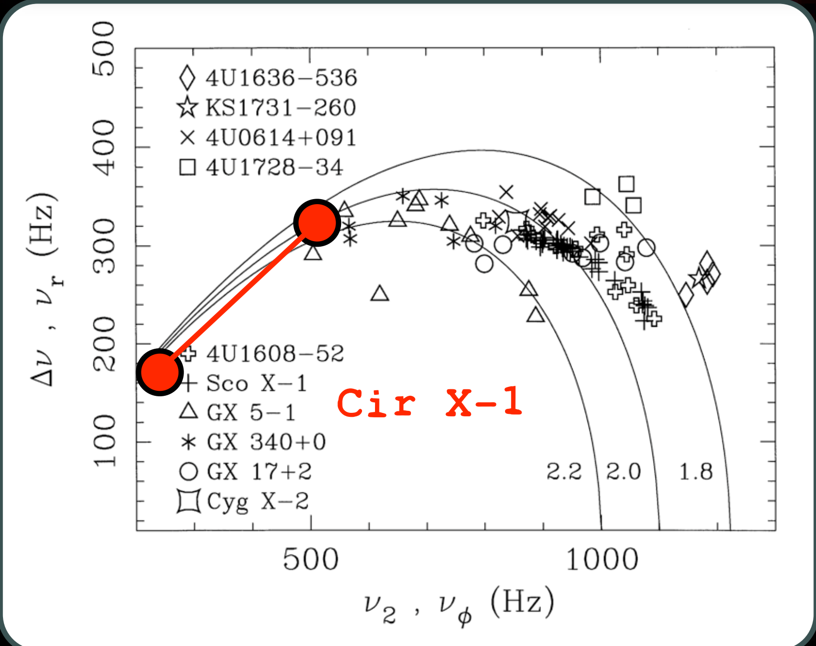
The circle is closed

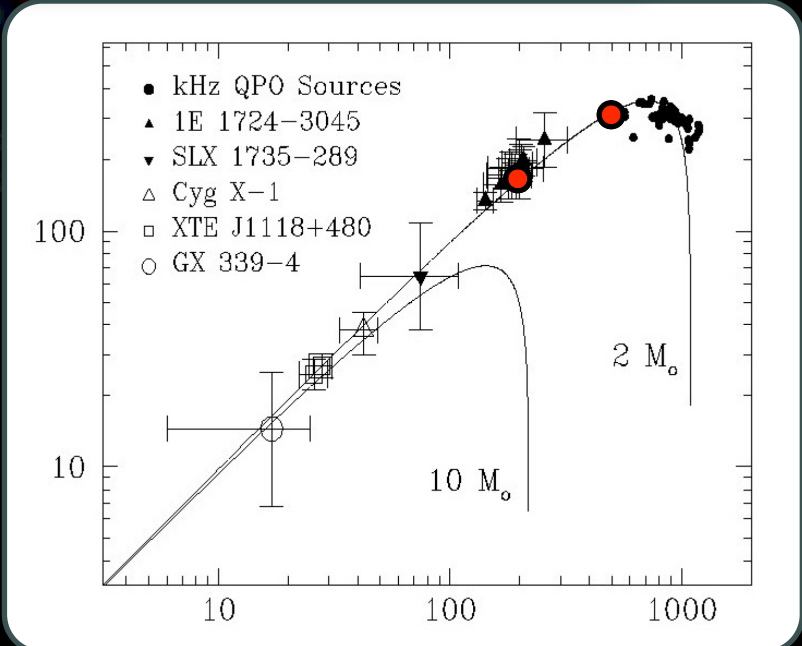
Theoretical models

- Identification of frequencies (low-ν QPO, 2 kHz QPO)
- Modulation process



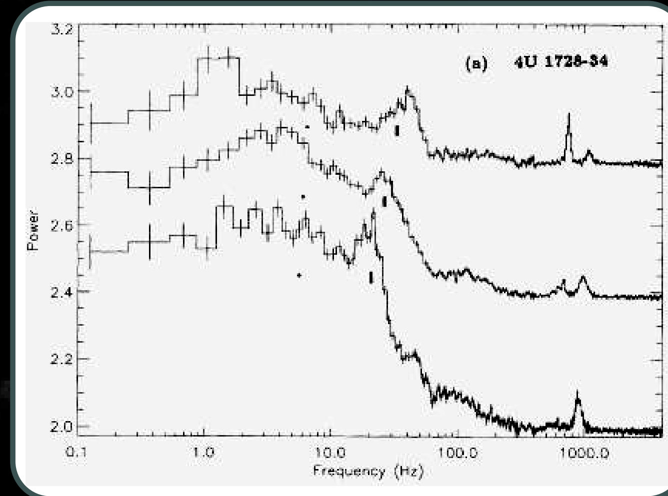
- Relativistic Precession Model
  - Basic GR frequencies: nodal precession, periastron precession, orbital





Theoretical models

- Identification of frequencies (low-ν QPO, 2 kHz QPO)
- Modulation process



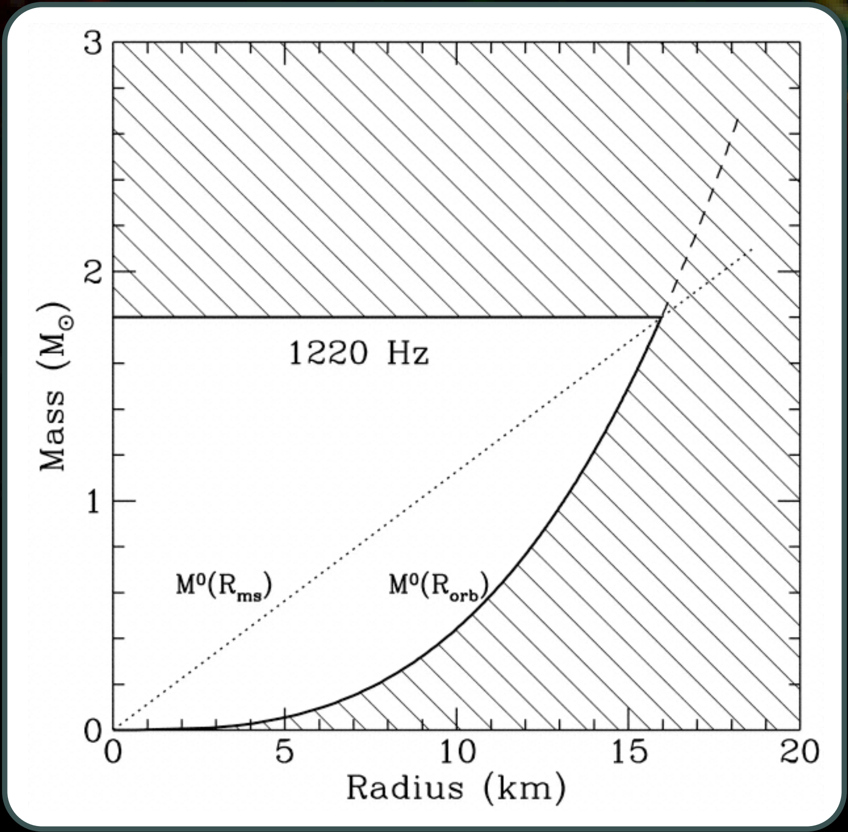
- Spin-resonance/sonic-point
  - Beat between orbit at sonic point and aximuthal structure at spin resonance
  - Interaction with spin
  - Needs pulsar
  - Also explains half $\Delta\nu$ or integer $\Delta\nu$

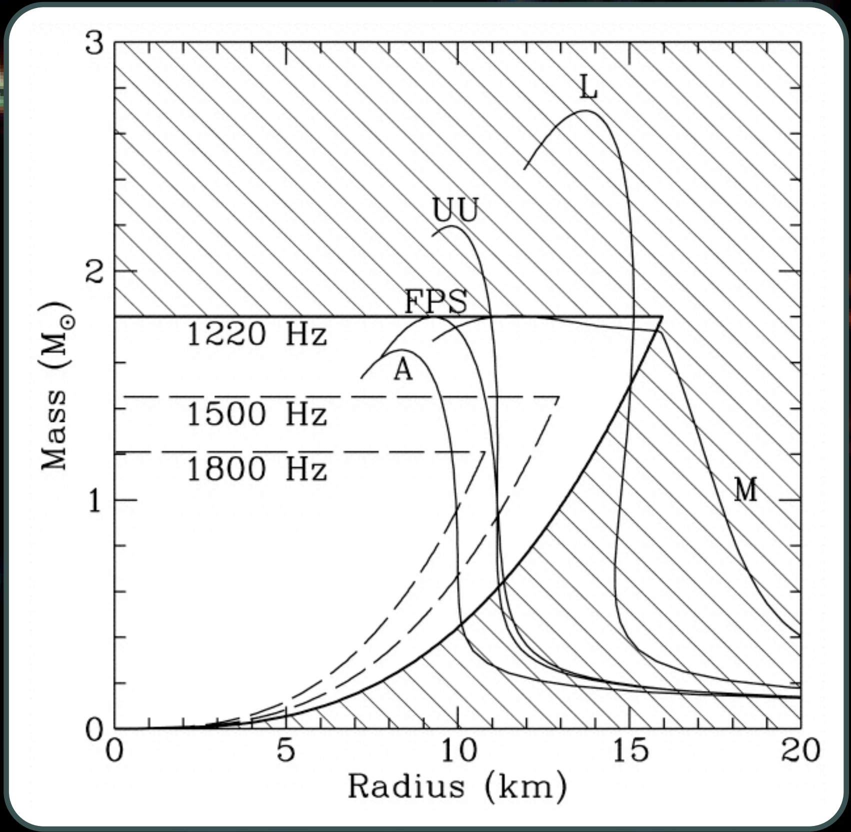
EOS of Neutron Matter

- If higher QPO is orbital:
  - NS smaller than orbit
  - Orbit larger than ISCO

$$M_{NS} = \frac{4\pi^2}{G} R_{orb}^3 \nu_{QPO}^2$$

$$M_{NS} = \frac{c^2}{6G} R_{orb}$$

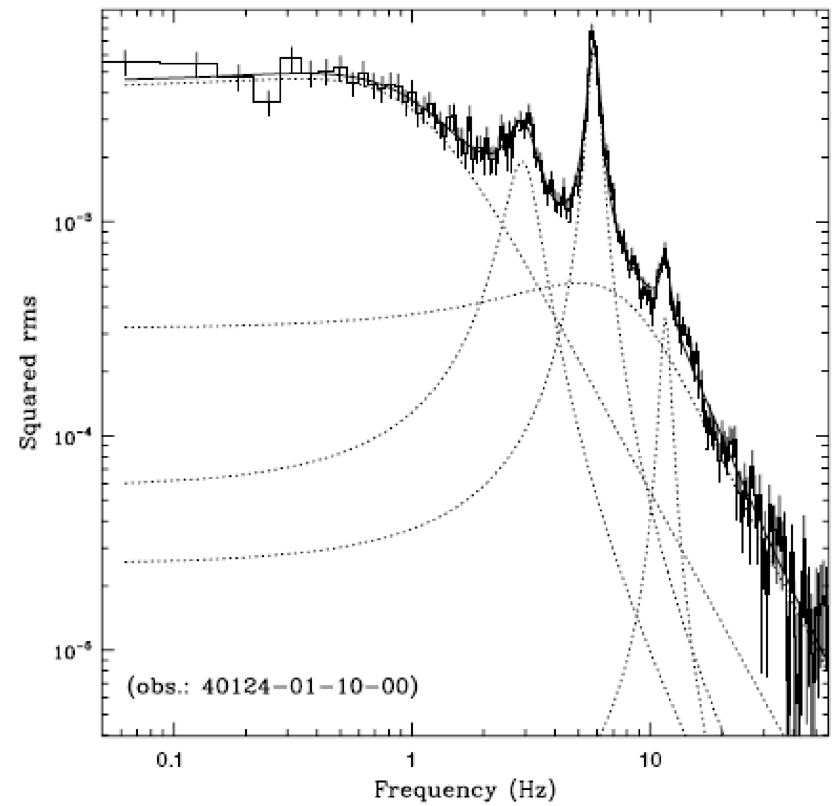


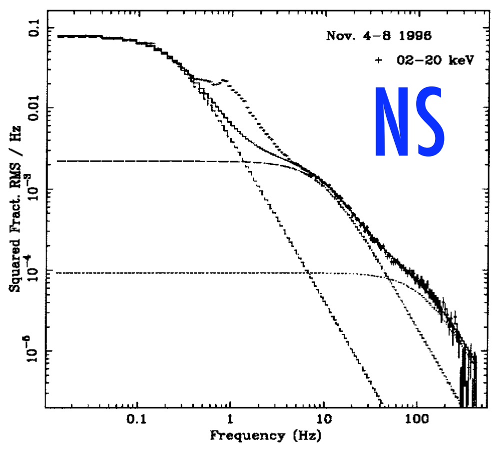


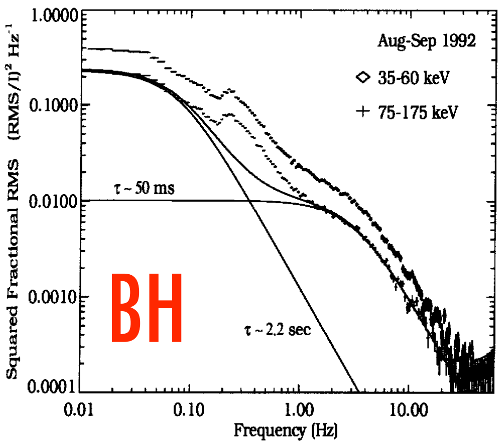
Black holes

Black-hole binaries: noise

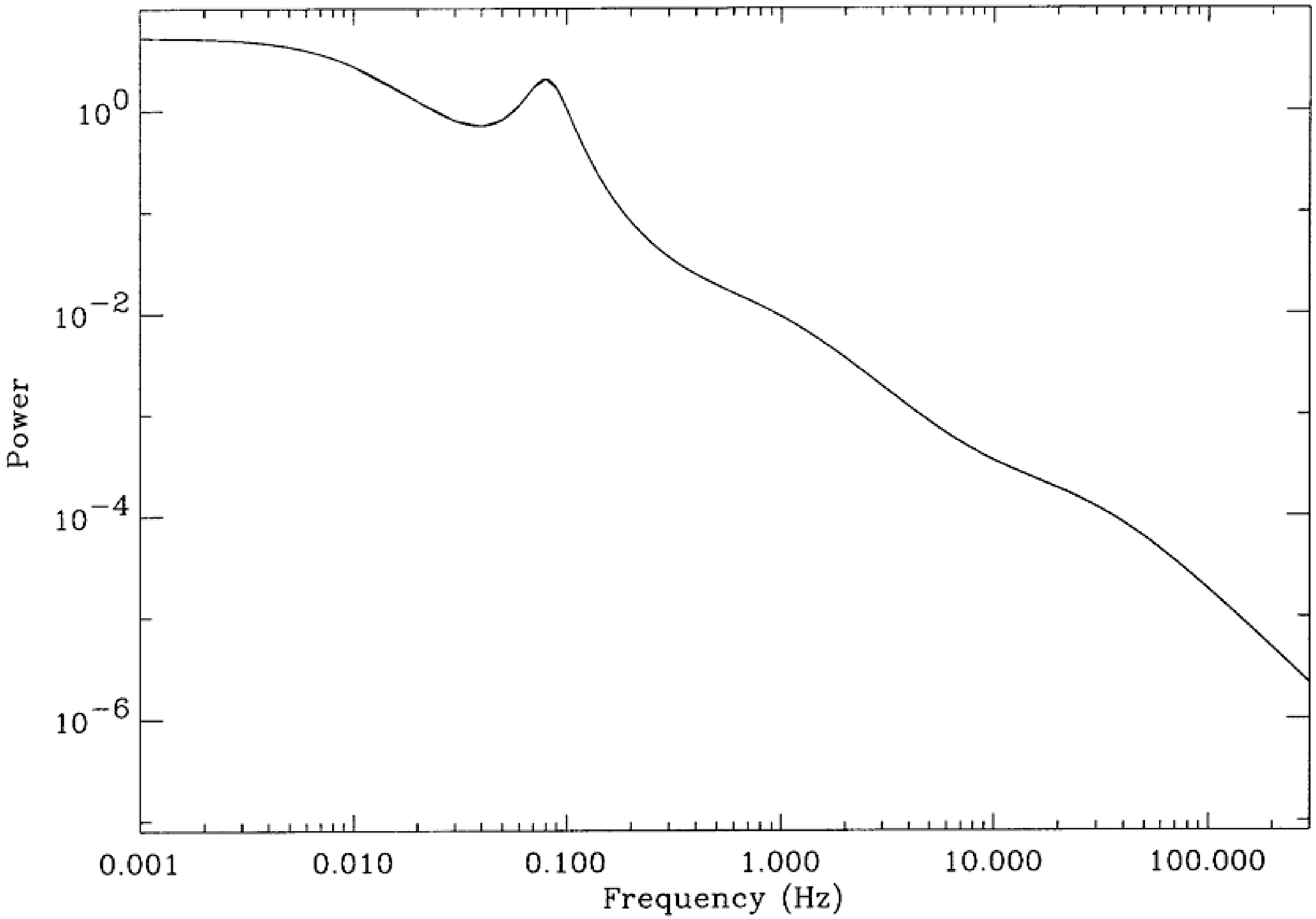
- In some states, flat-top noise
- Also low-ν QPO (next slide)
- Similar to low-L NS





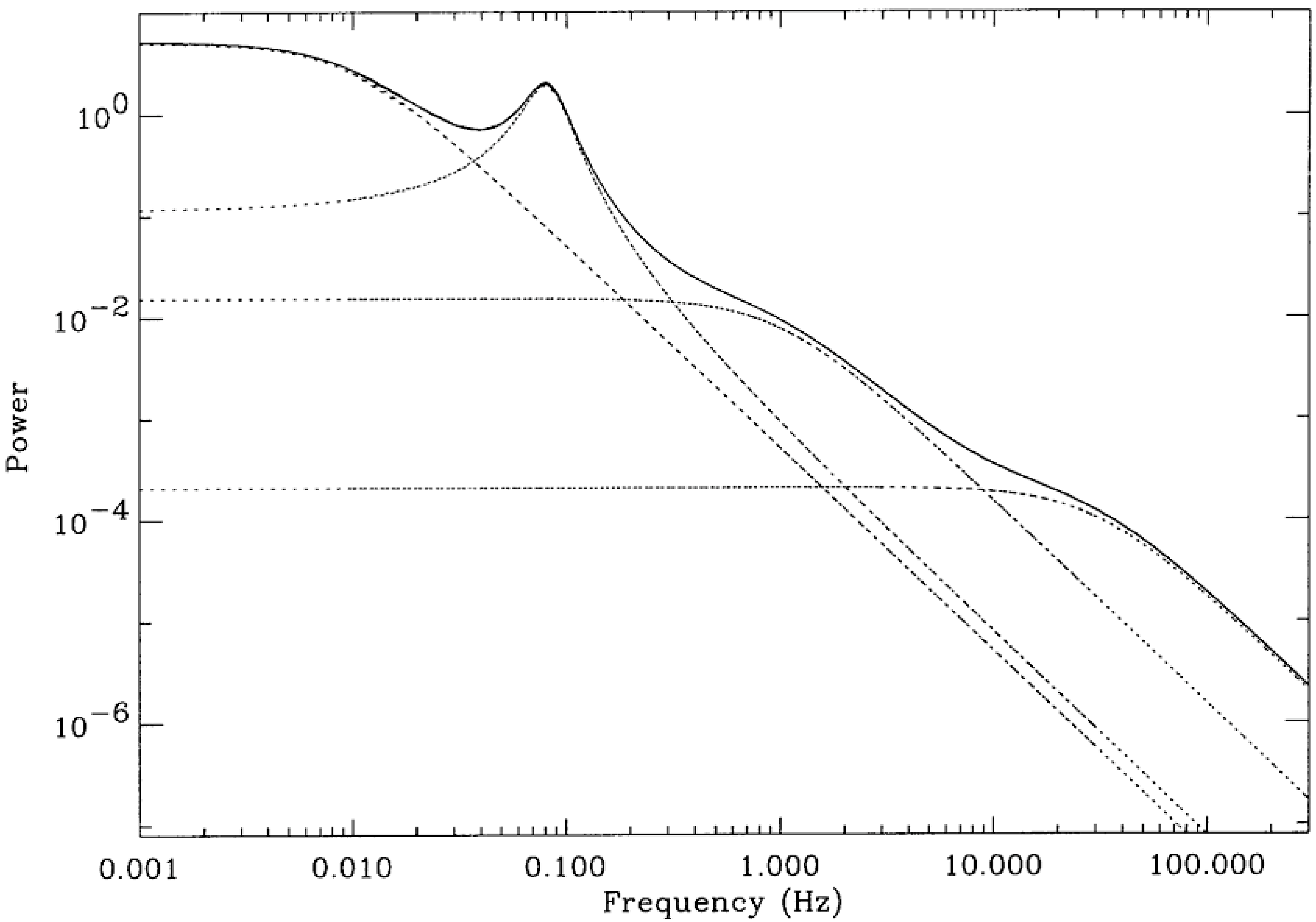


Black-hole binaries: noise



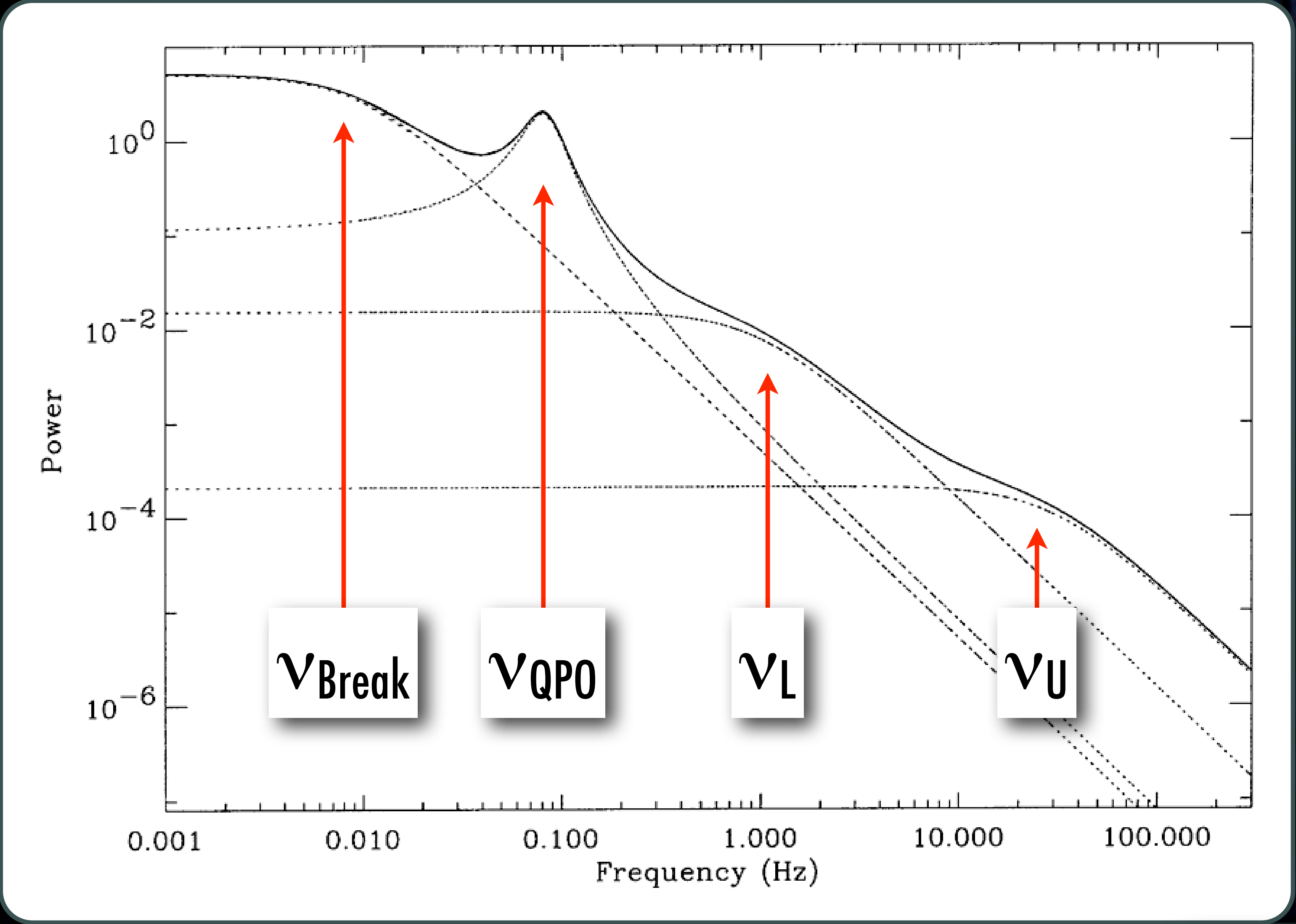
They all move!

Black-hole binaries: noise



They all move!

Black-hole binaries: noise



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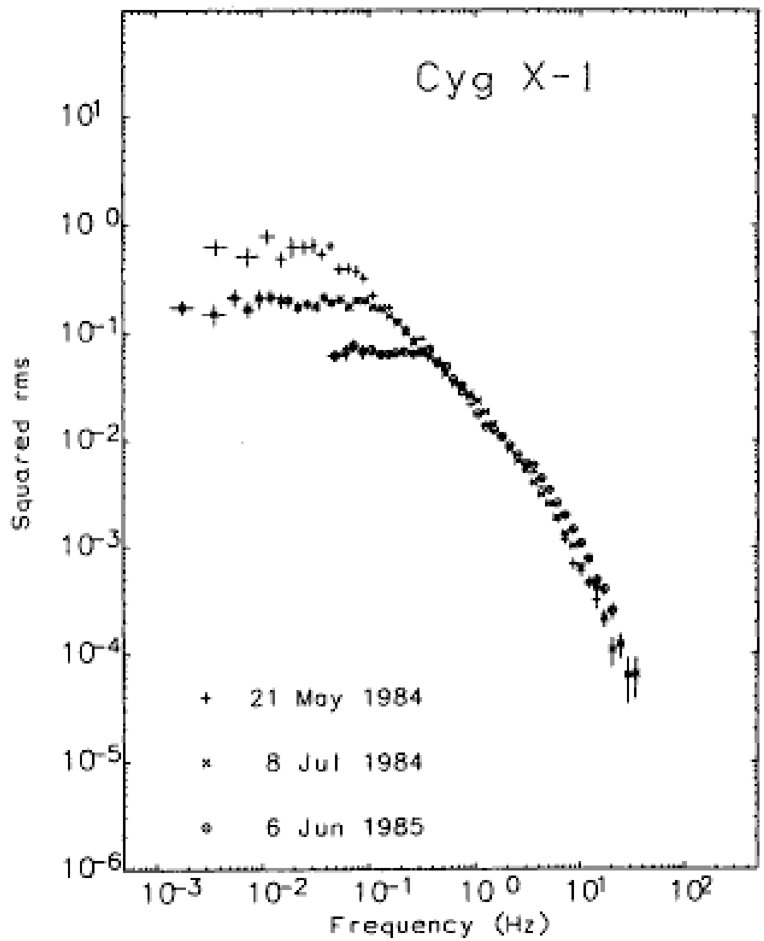
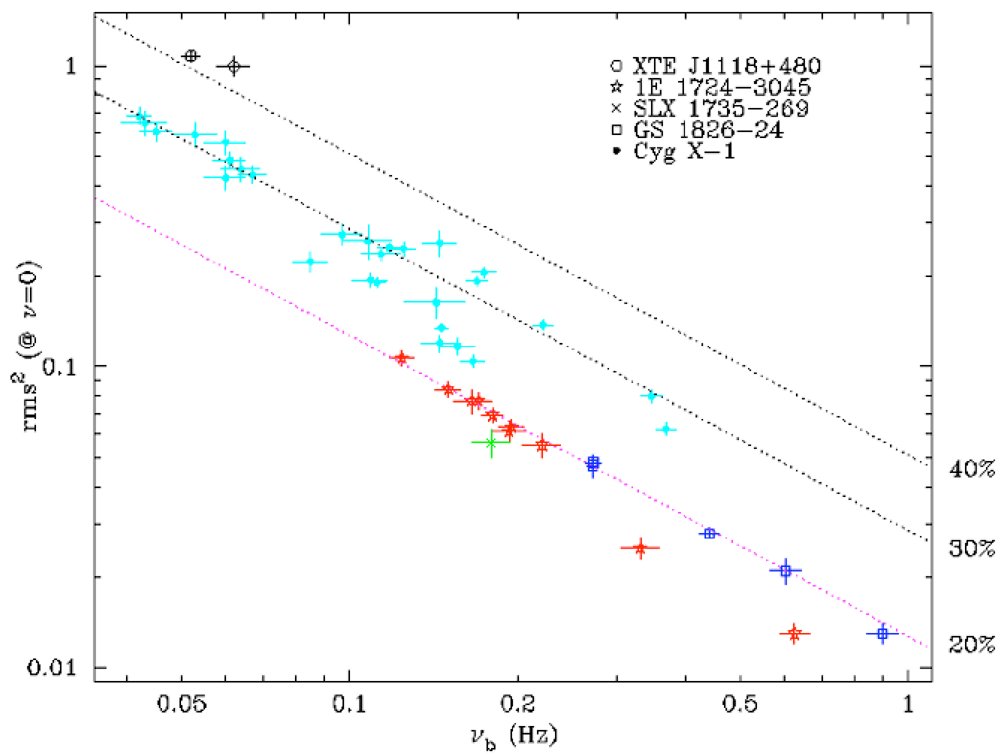
Black-hole binaries: noise



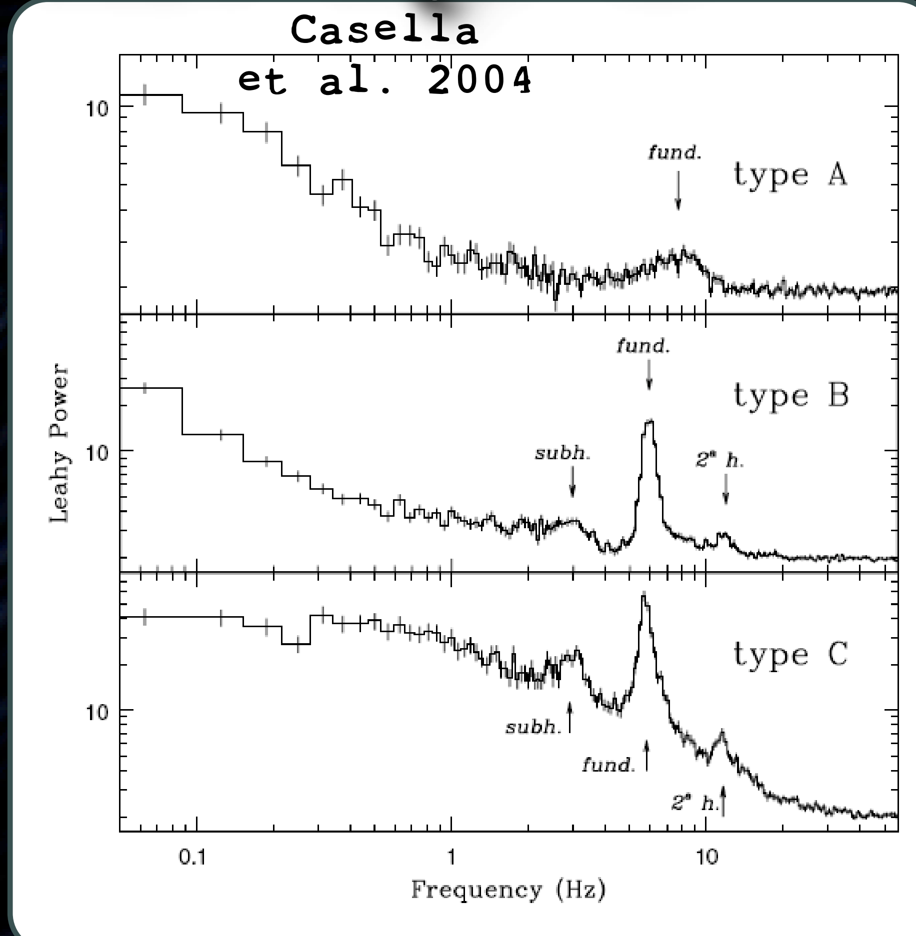
Belloni & Hasinger 1990

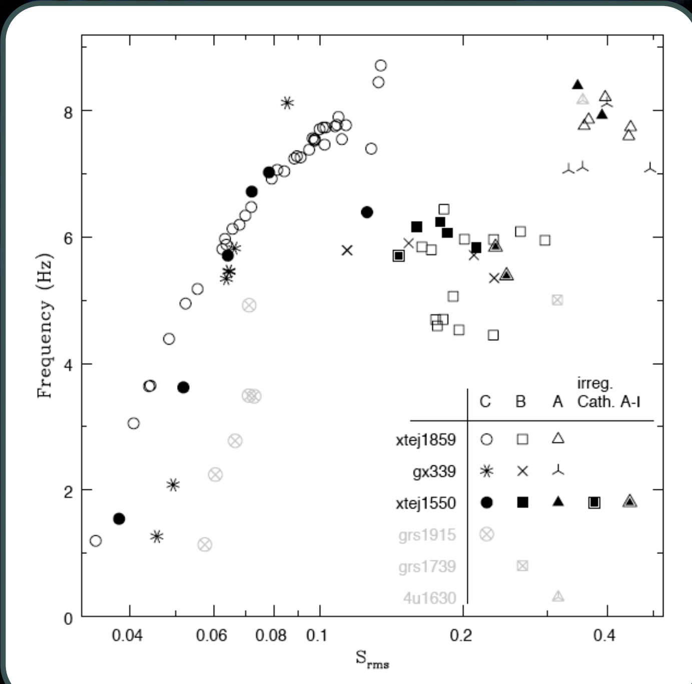


Belloni, Psaltis & van der Klis 1990

Black-hole binaries: QPO

- Low-frequency QPO as in NS
  - Type-C QPO
    - ★ Variable frequency 0.01-15 Hz
  - Type-A/B QPO
    - ★ Almost fixed frequency 4-8 Hz

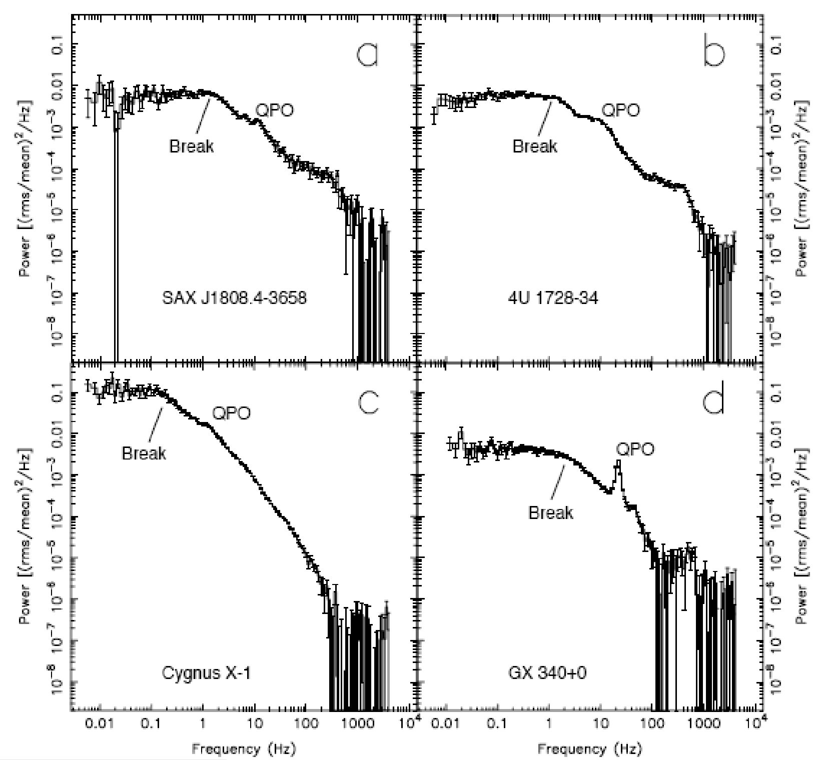


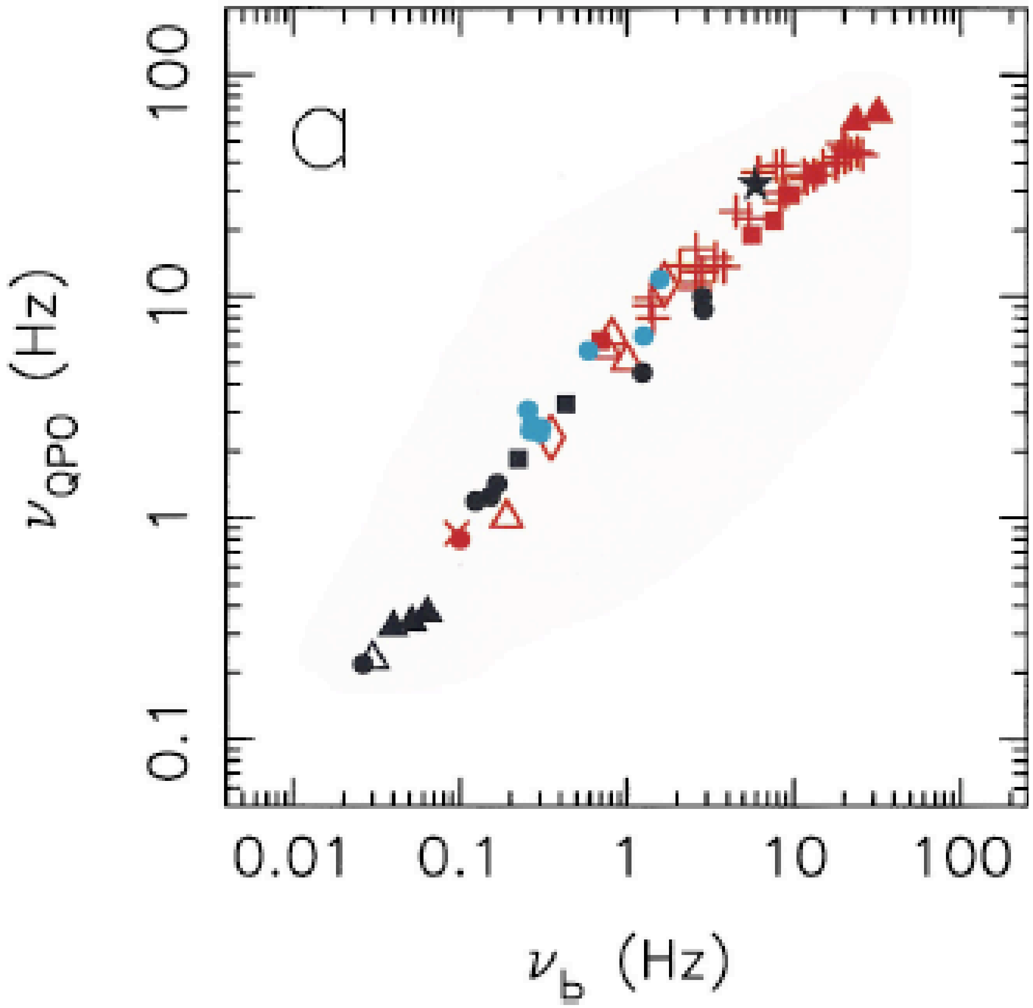


- ★ Type C - HBO
- ★ Type B - NBO
- ★ Type A - FBO

Global correlations

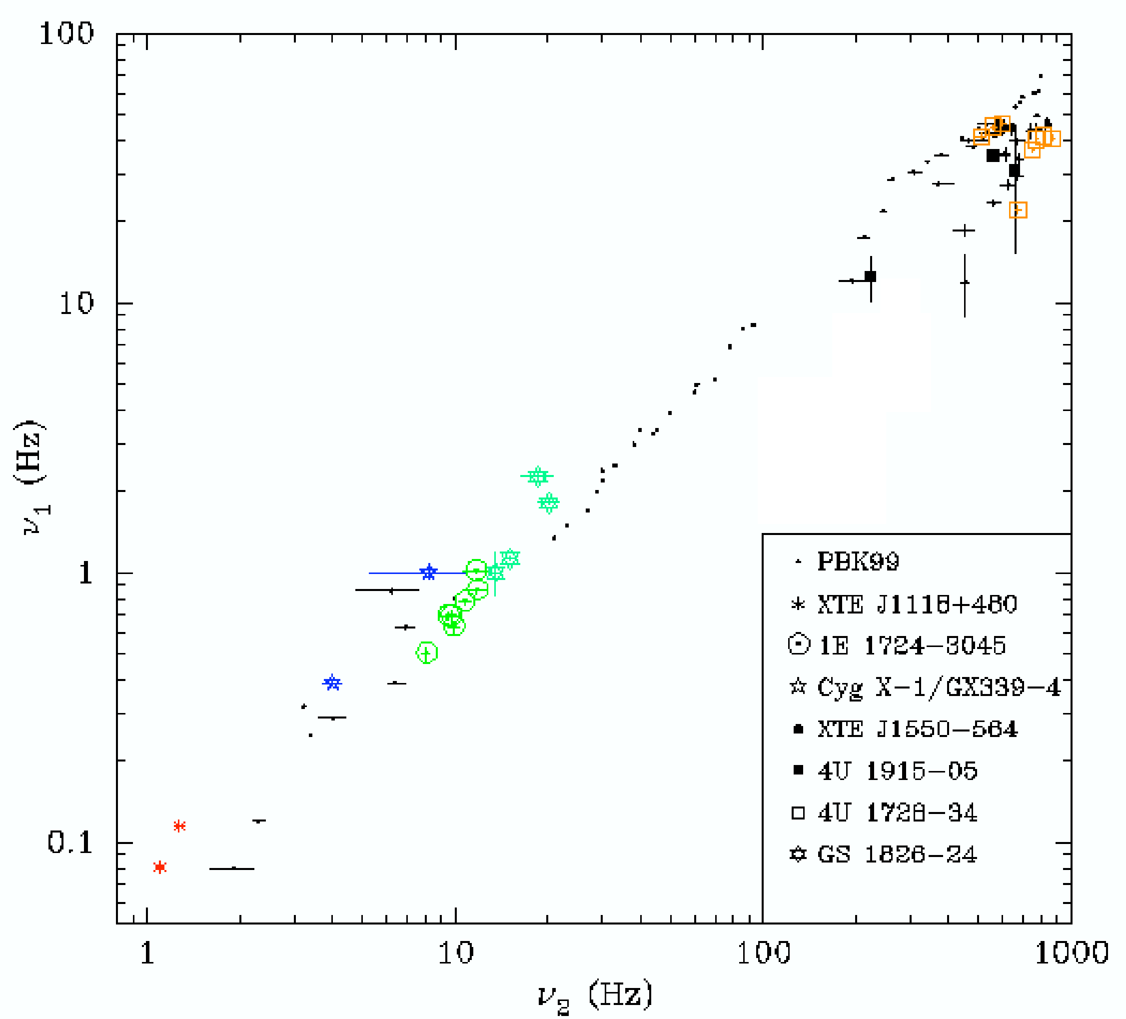
Wijnands & van der Klis 1999



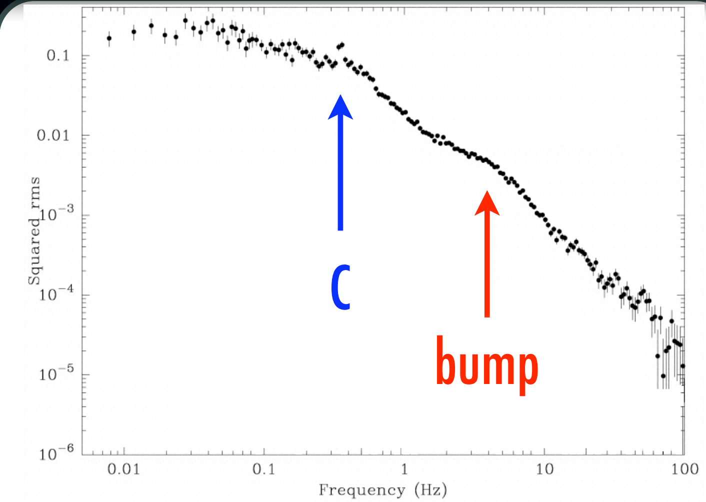


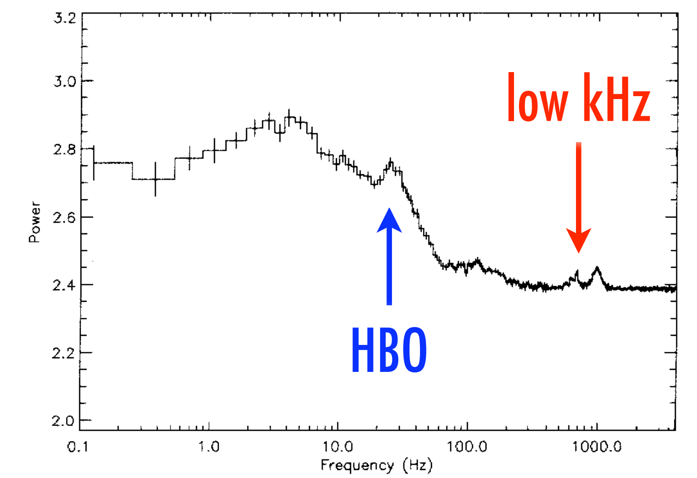
Noise and LFQPO connected

Global correlations II



Psaltis, Belloni & van der Klis 1999

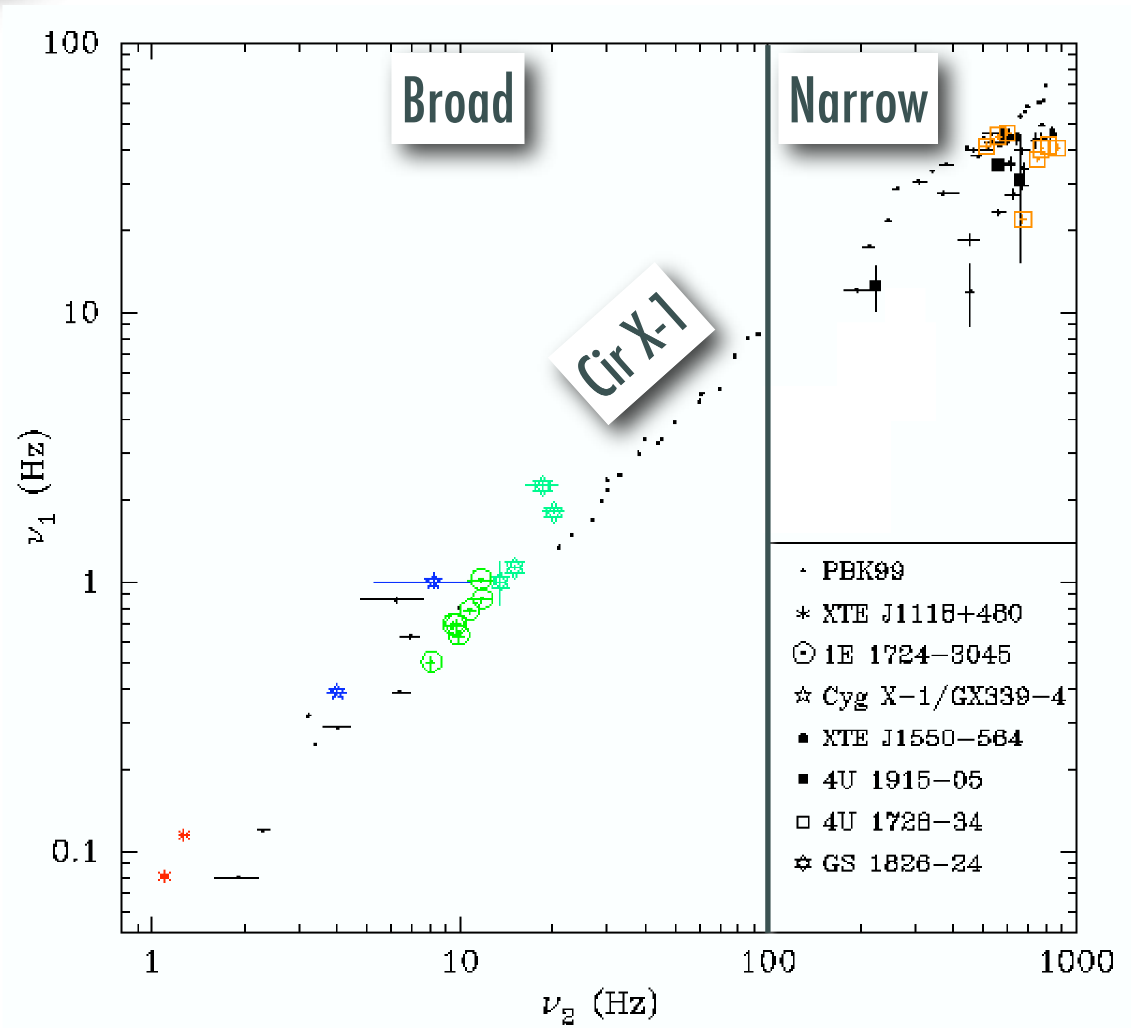


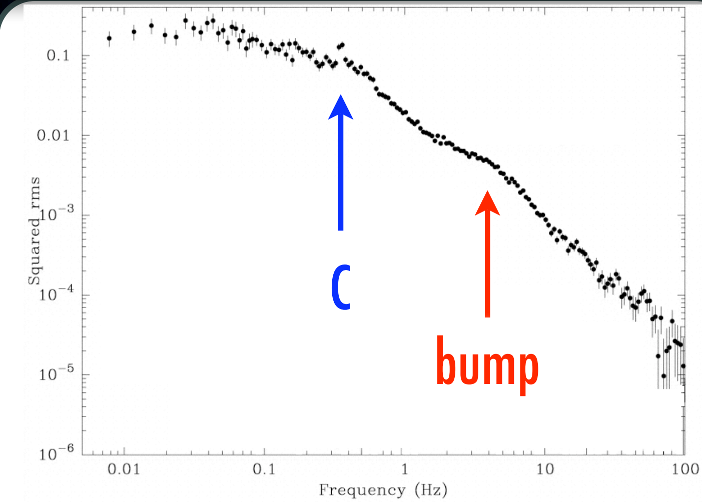


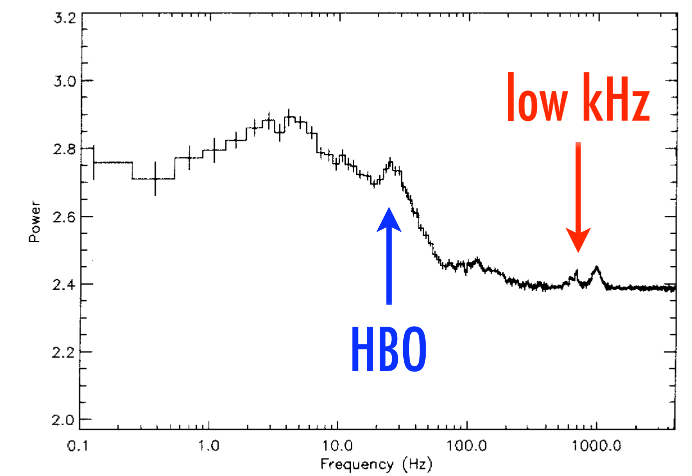
HFQPO & LFQPO & more... no B field?

Global correlations II

Psaltis, Belloni & van der Klis 1999

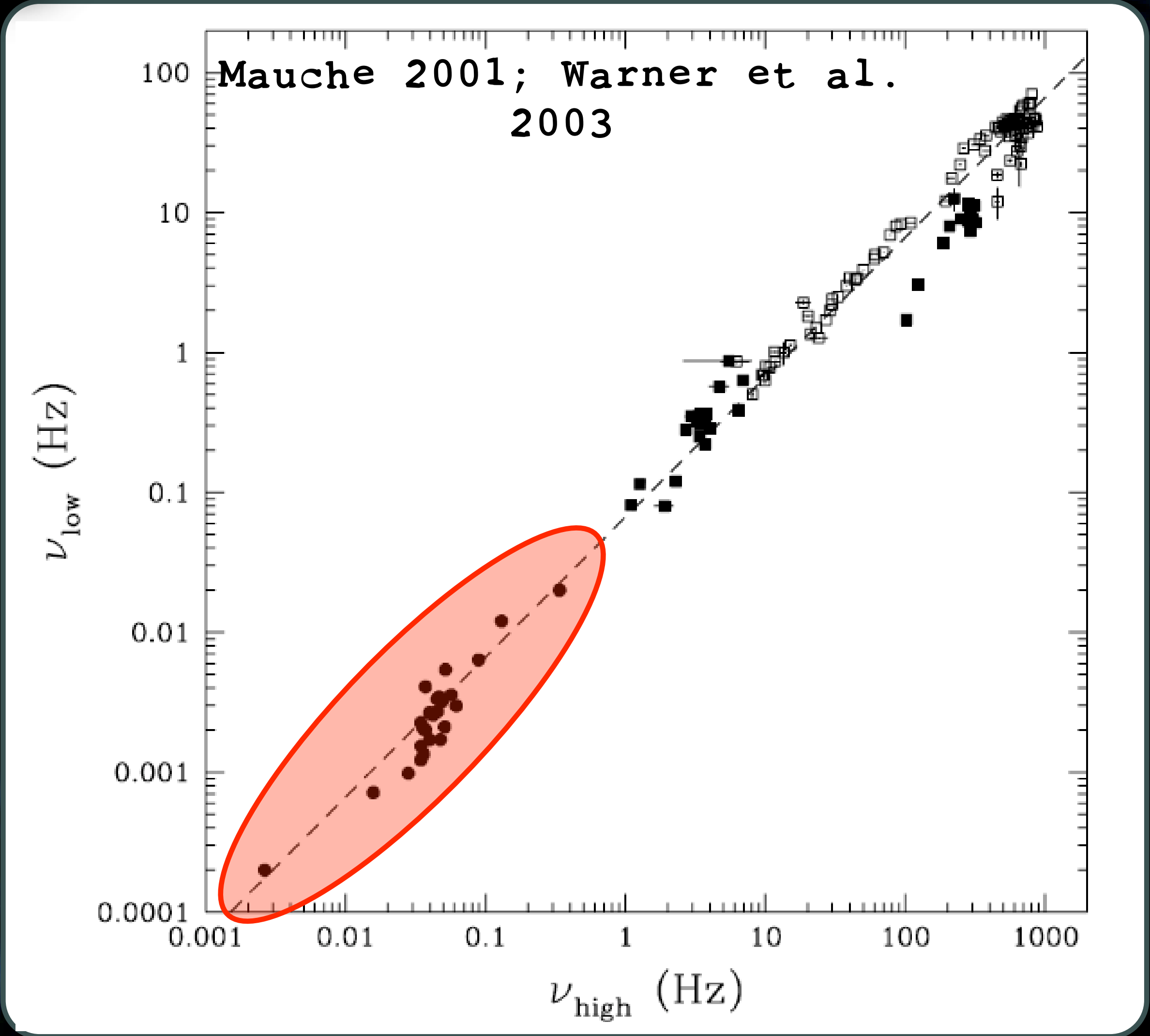


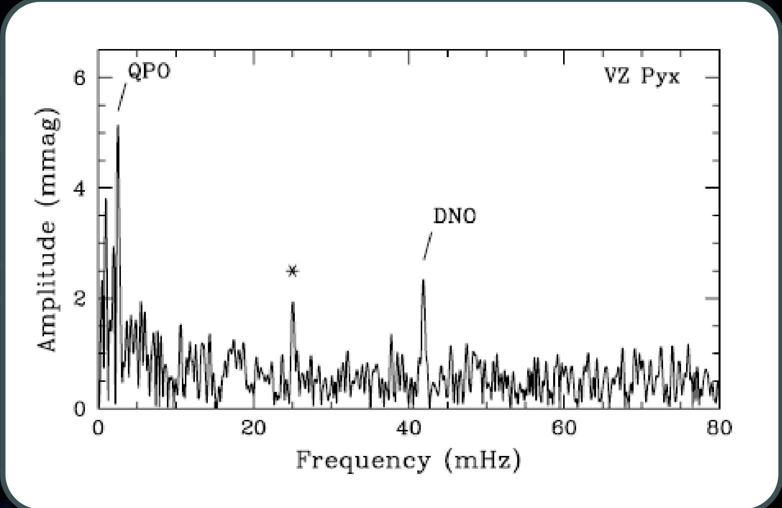




HFQPO & LFQPO & more... no B field?

Global correlations II+

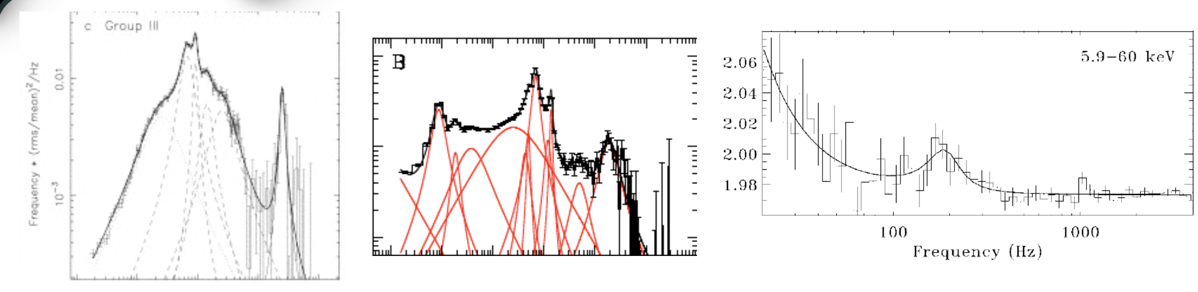




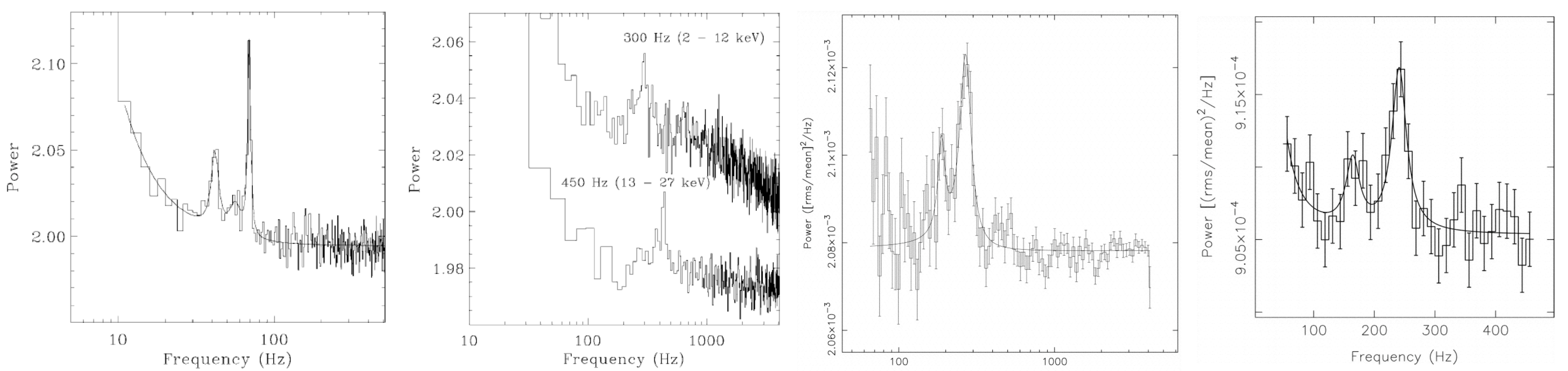
Also CVs... no GR effects?

BH high-frequency QPOs

- Frequencies 30-450 Hz
- Weak and rare
- Fixed frequencies
- Some (4/7) come in pairs
- GRS 1915+105 has more
- Different from NS kHz QPO



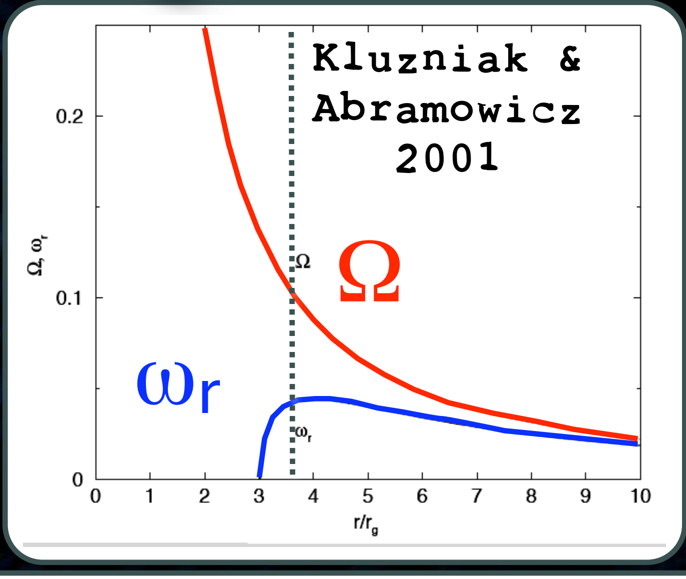
XTE J1650-500 4U 1630-47 XTE J1859+226

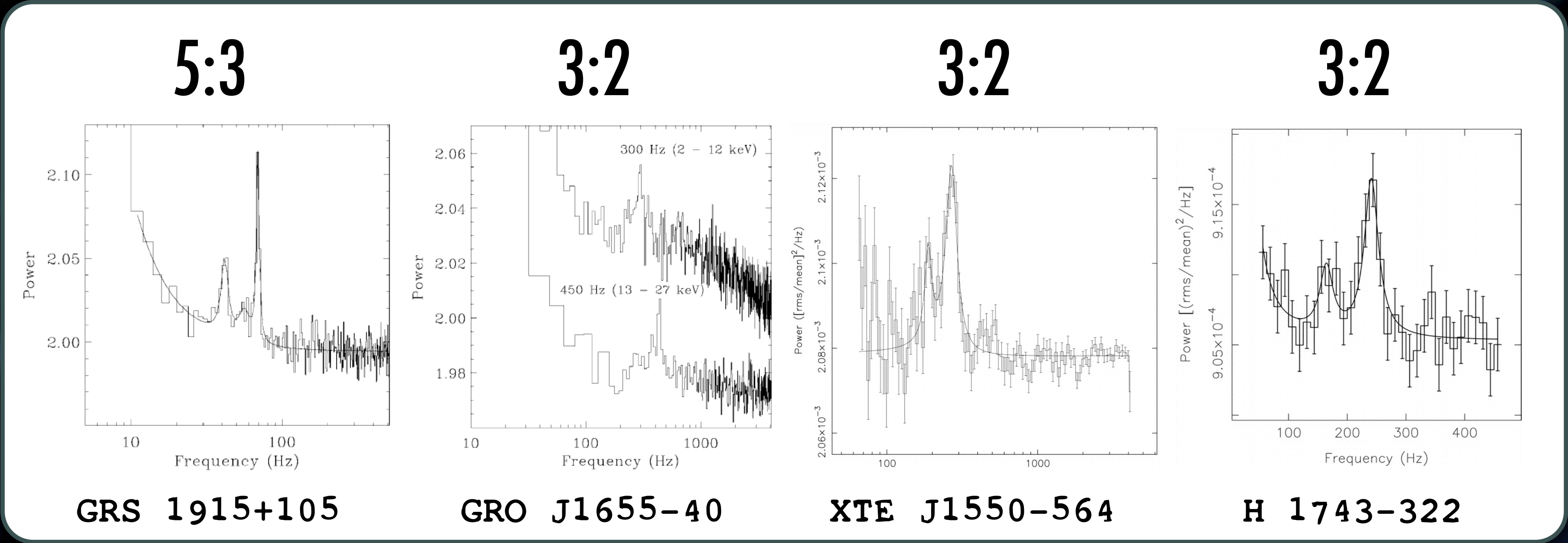


GRS 1915+105 GRO J1655-40 XTE J1550-564 H 1743-322

BH high-frequency QPOs

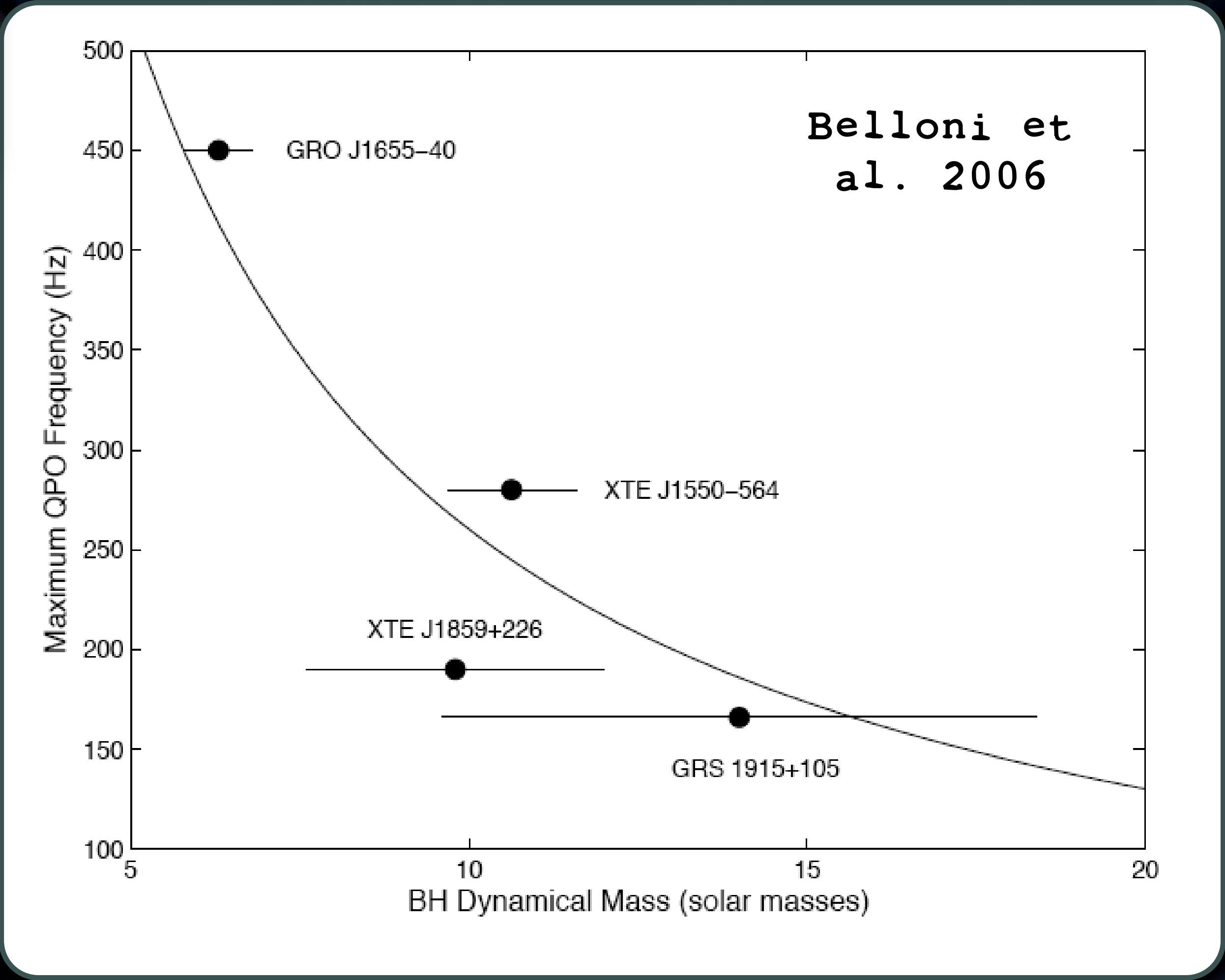
- Pairs appear at certain ratios
- Resonance model developed
- Still few points available





BH QPO resonances

- Highest frequency orbital
- Should scale with mass
- Some masses are known



Black-Hole Binaries

spectra/timing/states/radio

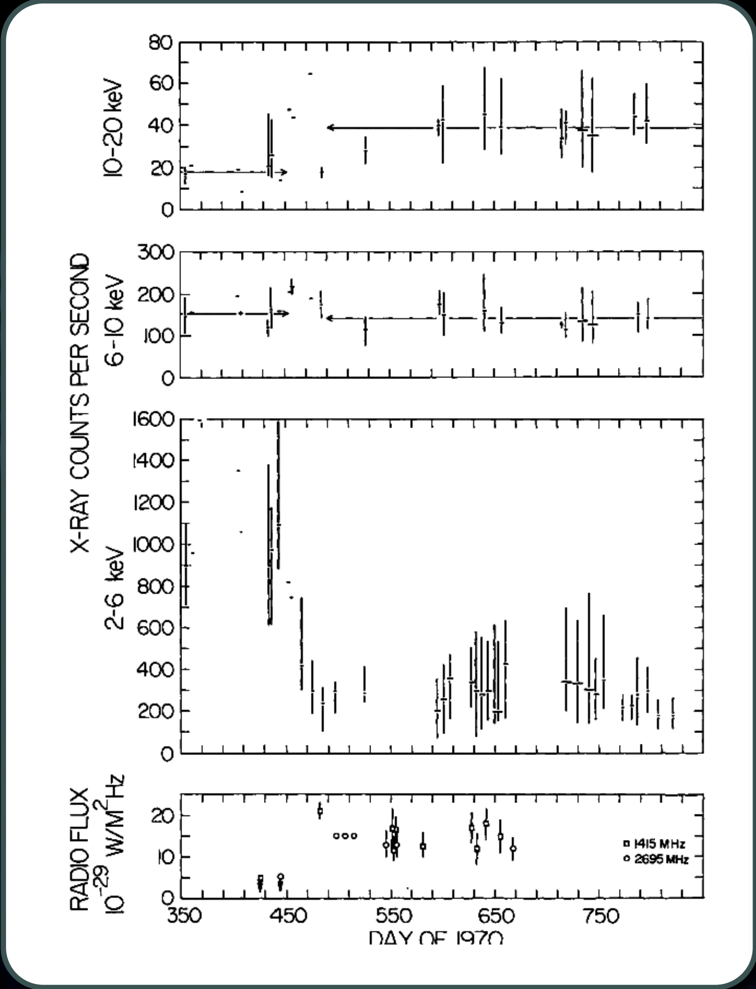
Soft and Hard States

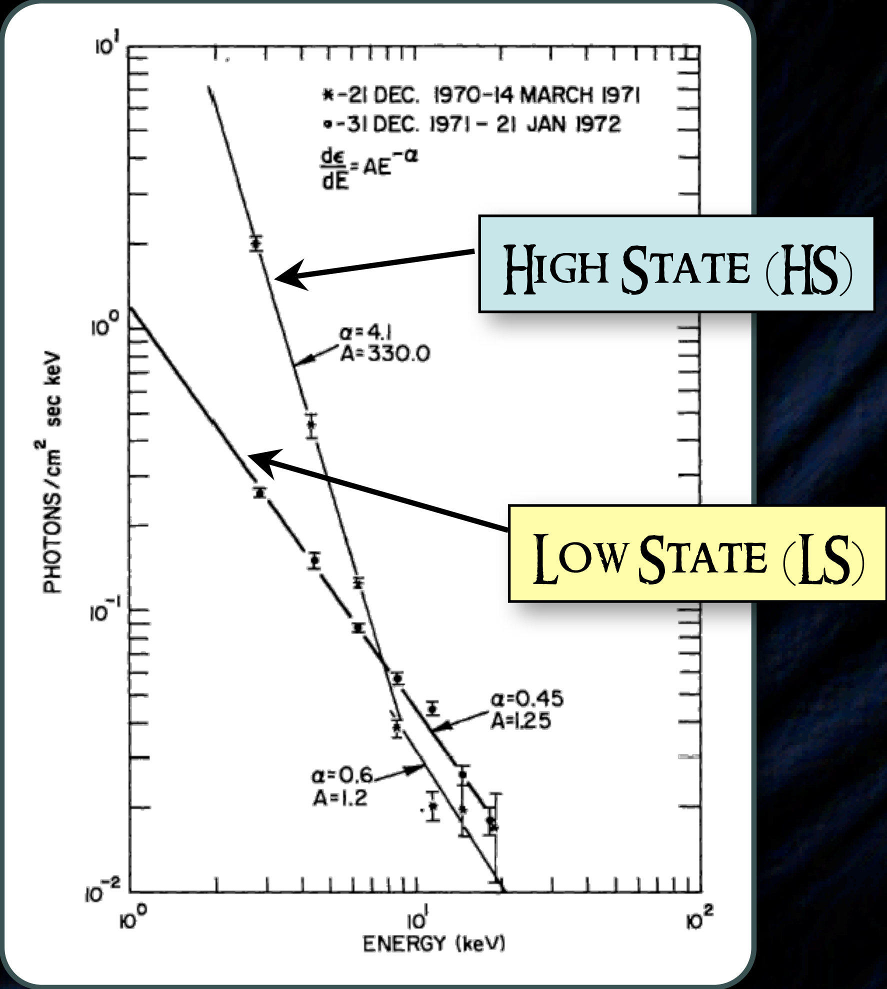
- Two main states are well studied
  - Hard State
  - Soft State
- Do they have anything in common?
- Spectra, variability, jet properties

Soft and Hard States

- Known since Uhuru

Tananbaum et al. (1971)



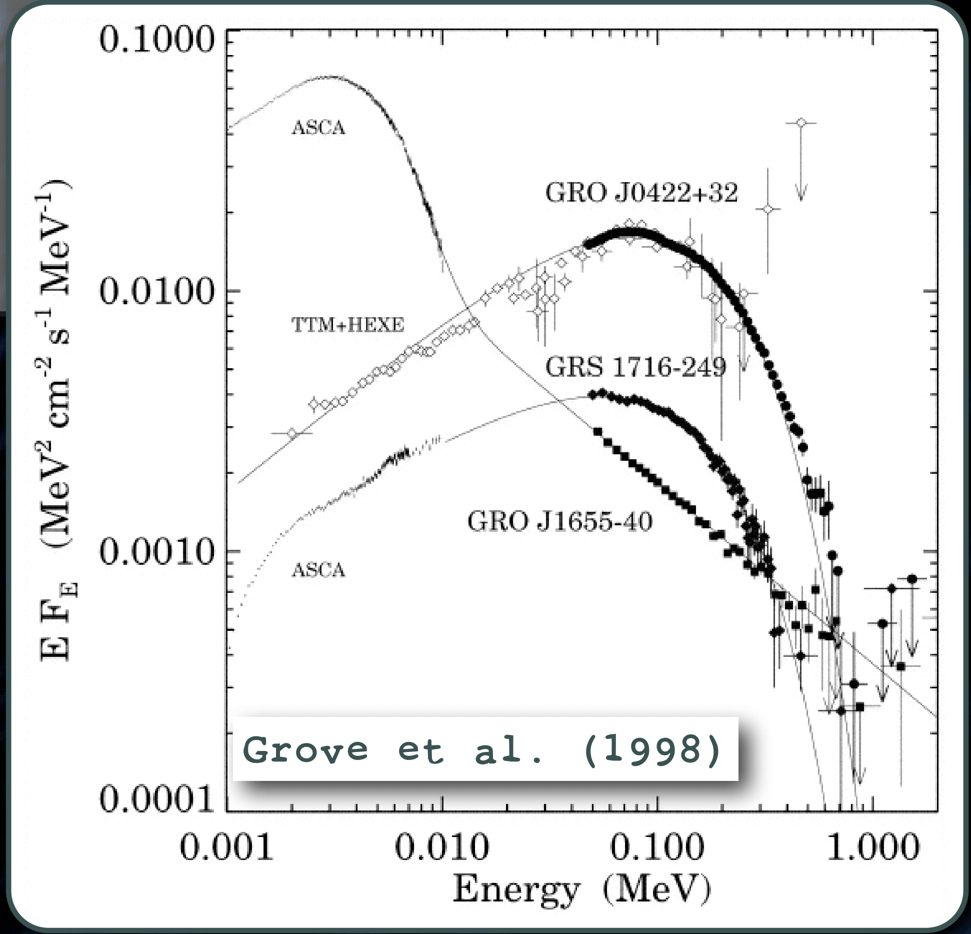


Energy Spectra

- Hard State: hard (Comptonization?) component, very soft (if any) disc
- Soft State: disc + weak steep power law

Cutoff vs. no cutoff

Same component?

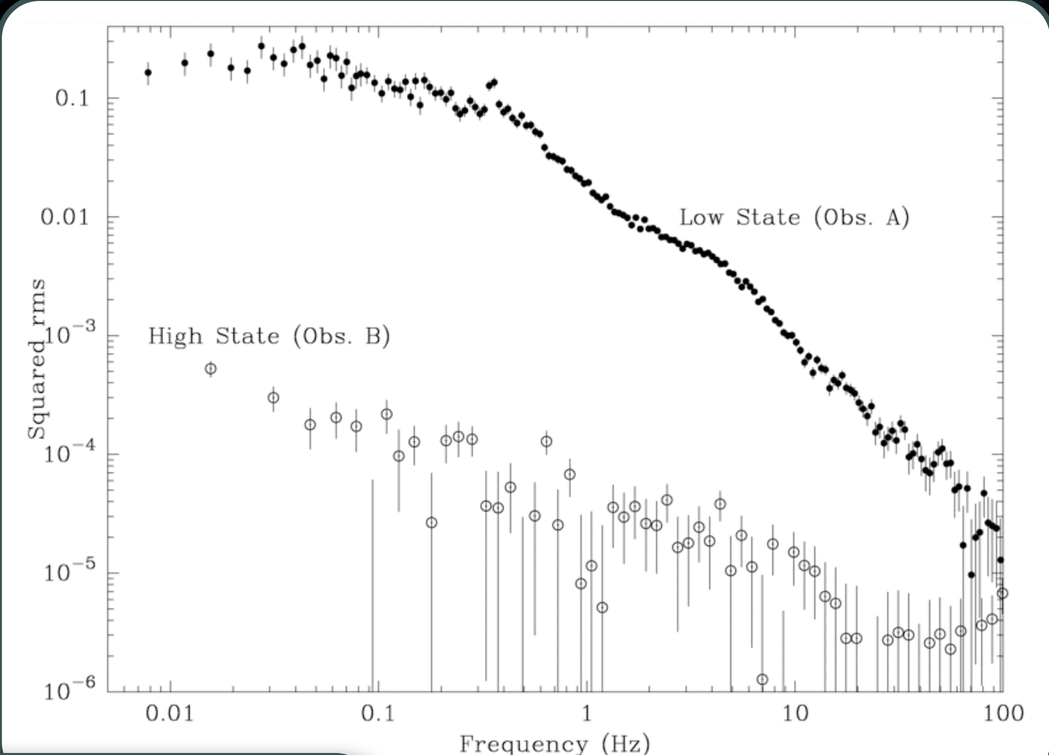


Fast Timing Properties

- Hard State: very strong (30-50%) noise, low-frequency QPOs
- Soft State: weak power law

Disc should not be noisy

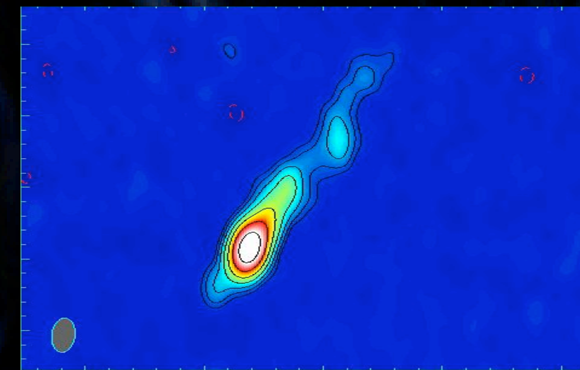
Same component?

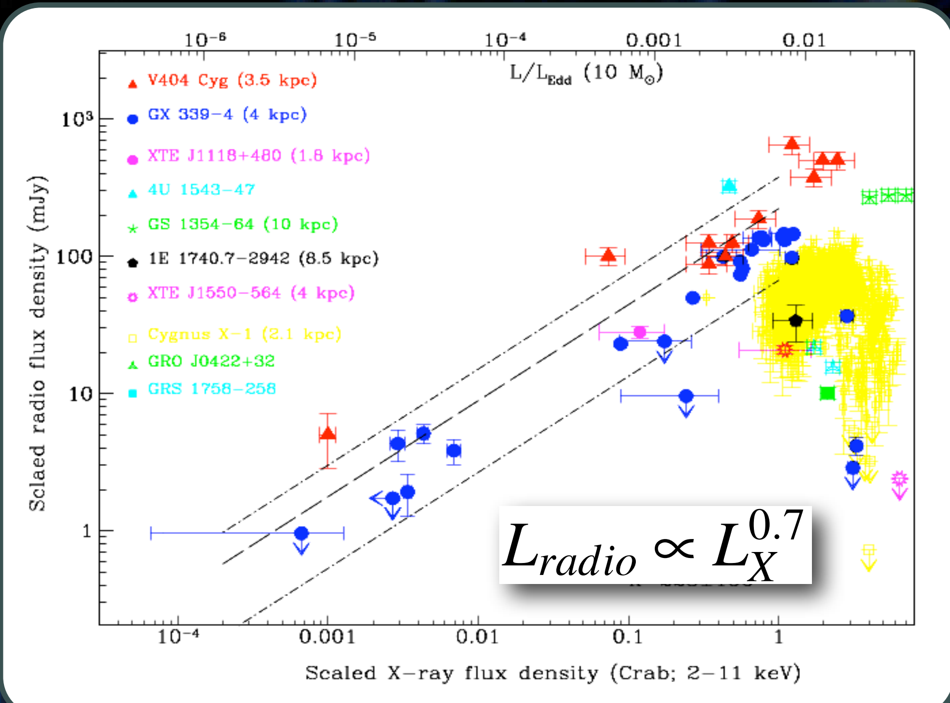


Belloni et al. (1999)

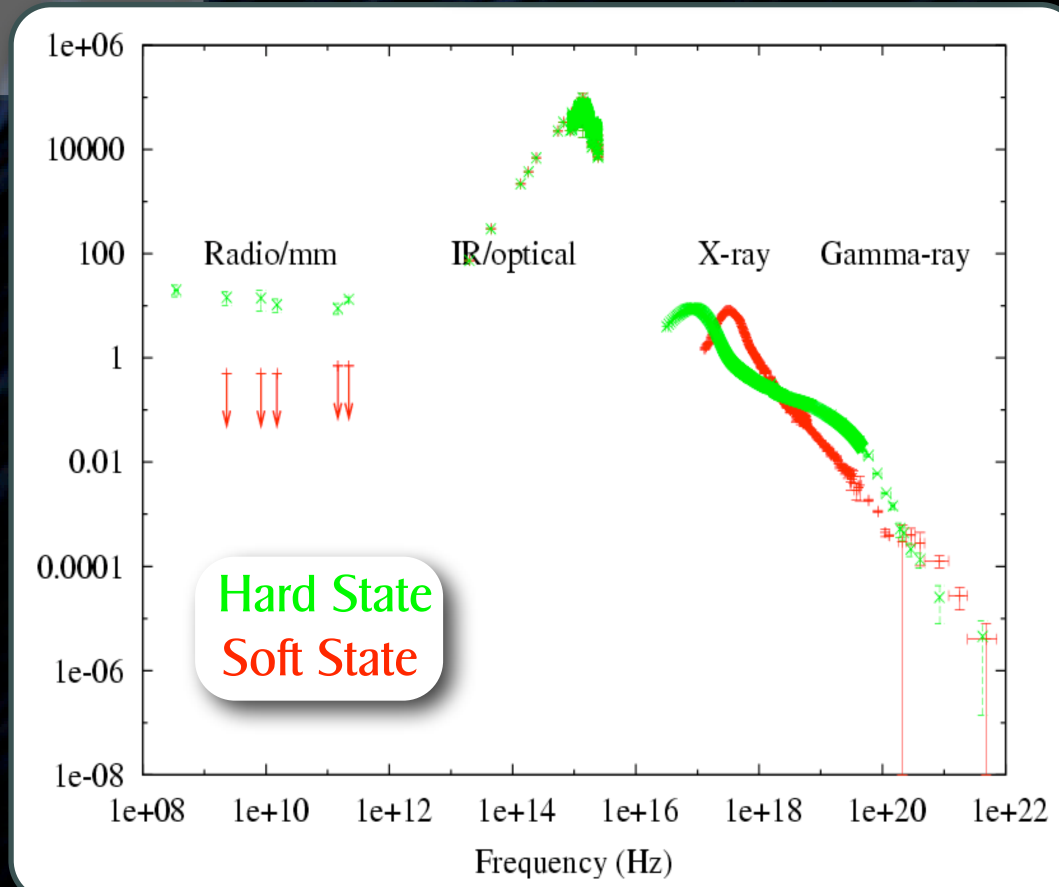
Radio Properties

- Hard State: radio emission, compact jets
- Soft State: radio quiet - no jet?



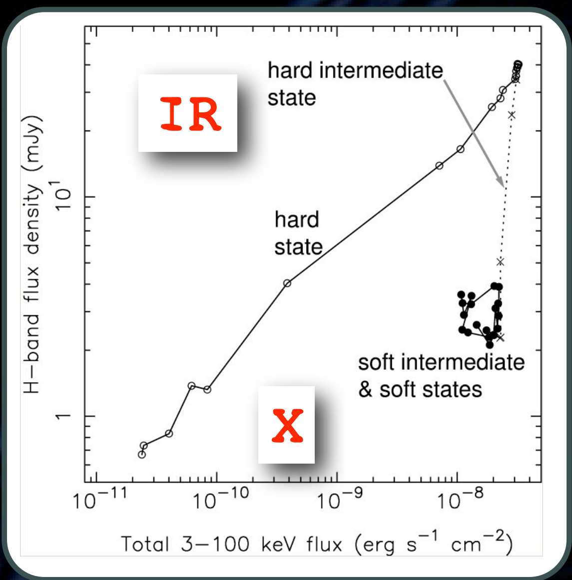


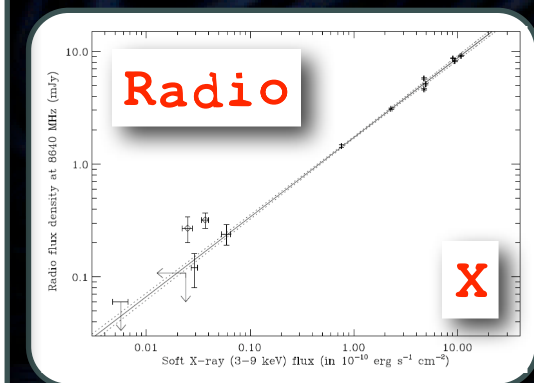
Gallo et al. (2003)

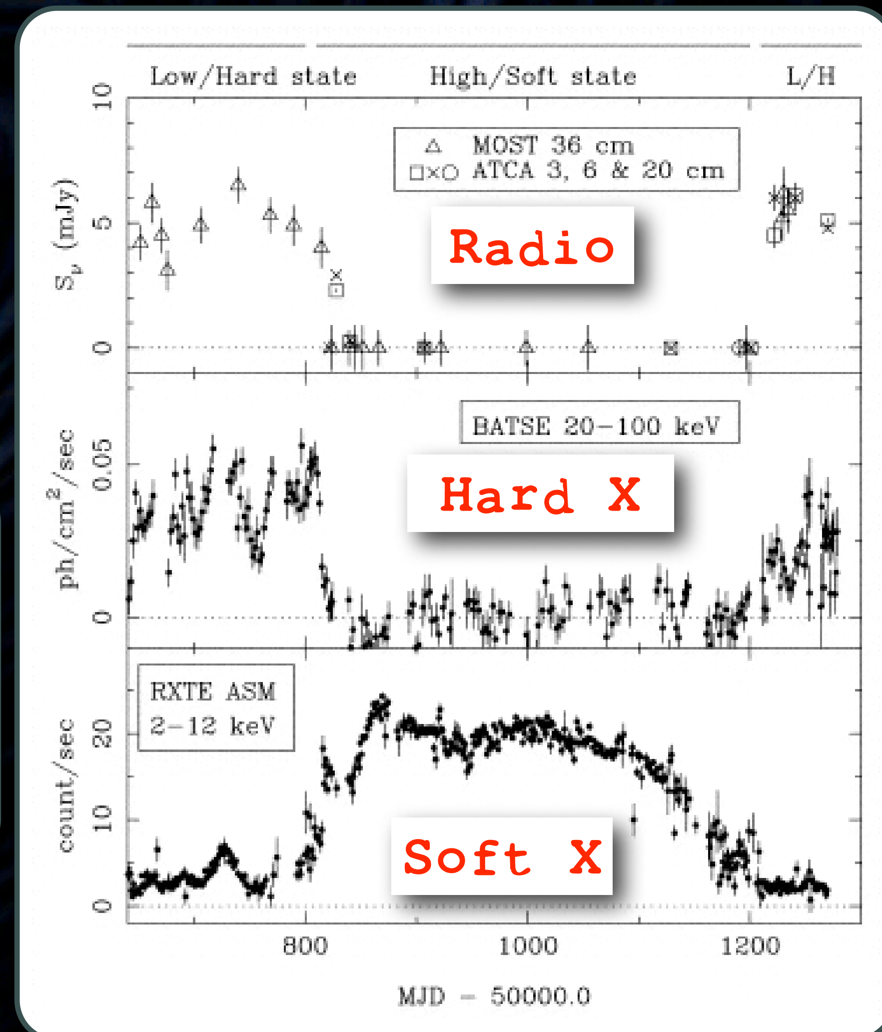


Radio Properties

- Hard State: correlations
- Soft State: radio quiet







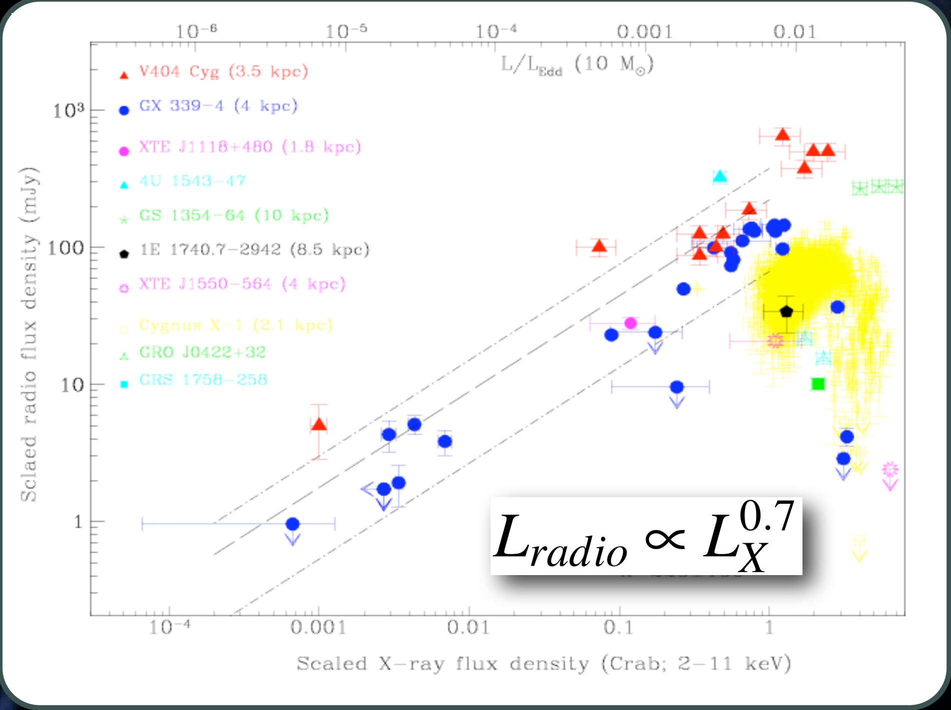
Homan et al. (2005)

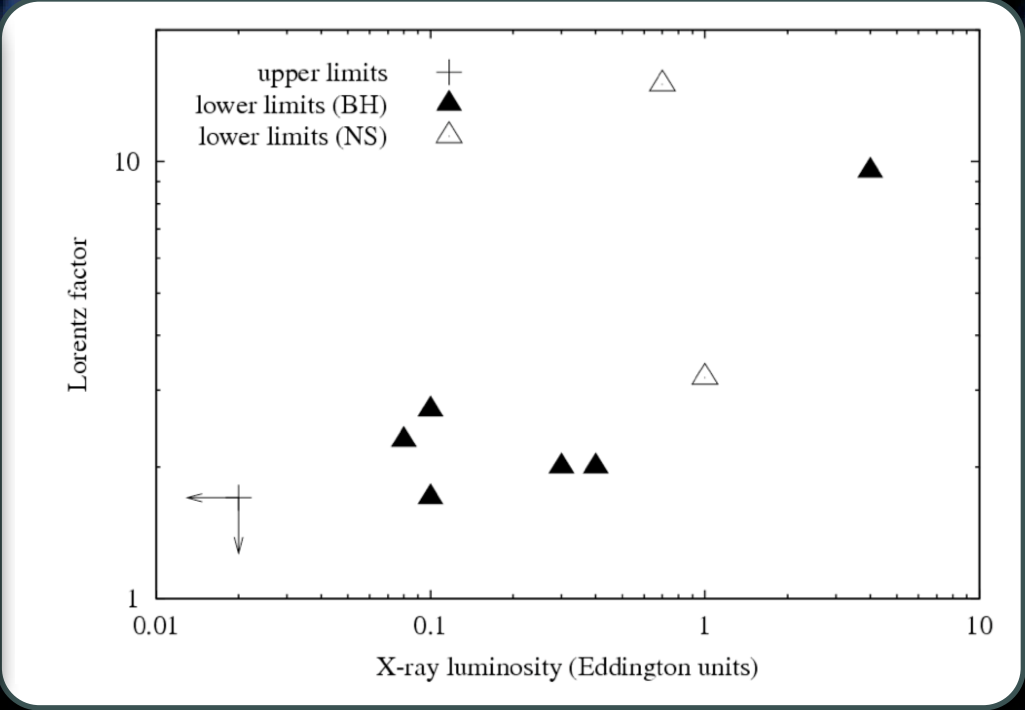
Corbel et al. (2003)

Fender et al. (1999)

Radio Properties

- Hard State: mildly relativistic



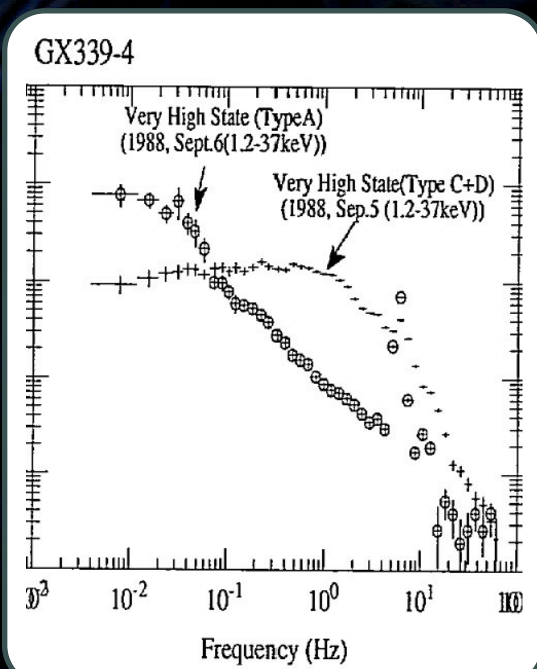


Gallo et al. (2003)

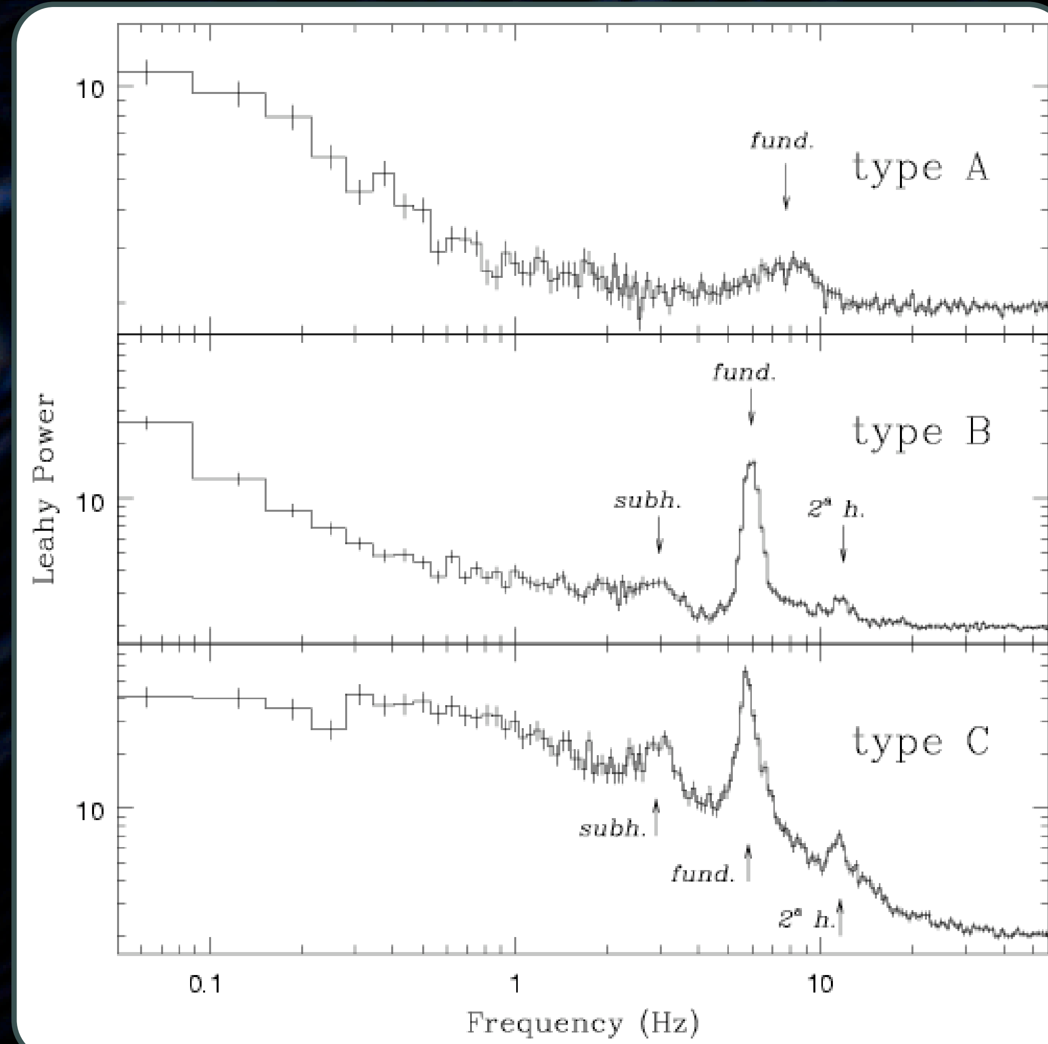
Fender, Belloni & Gallo (2004)

Other States

- Very-High State
- Intermediate State
- Steep-Powerlaw State



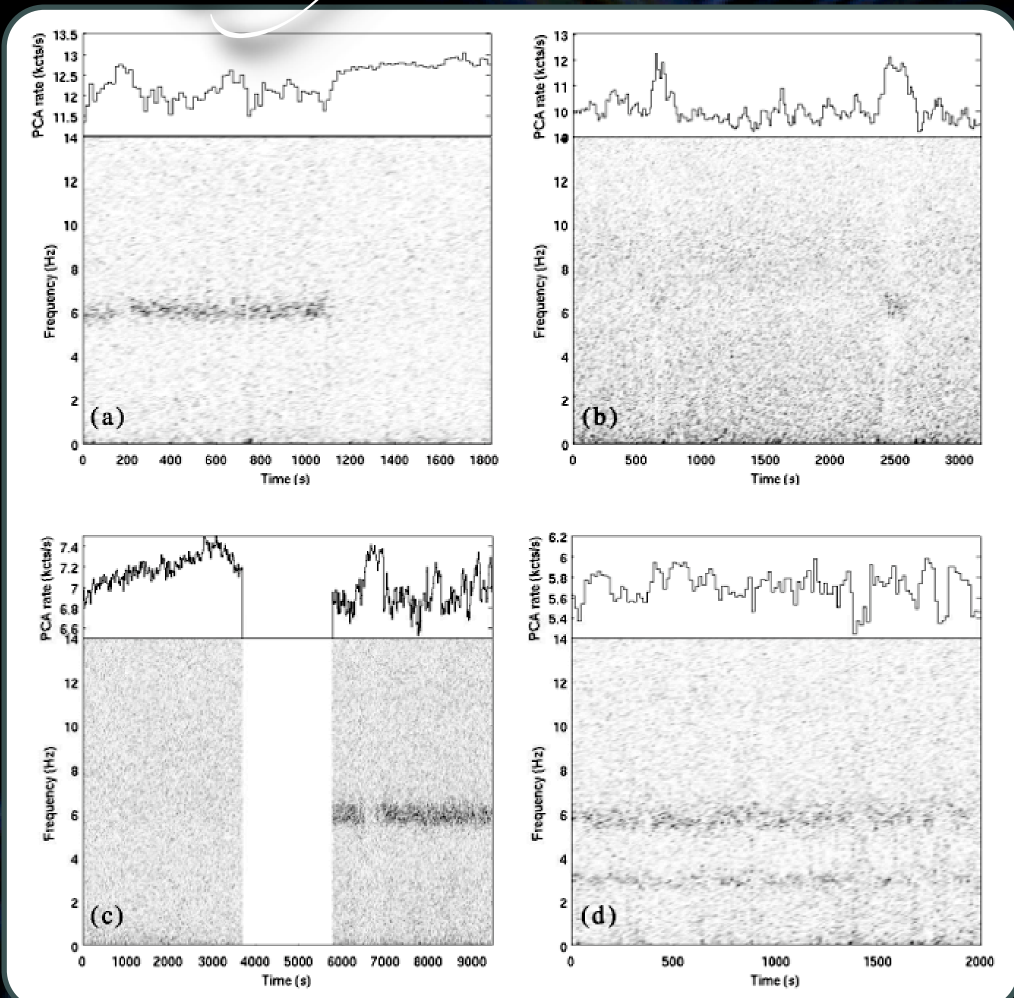
Miyamoto et al. (1991)



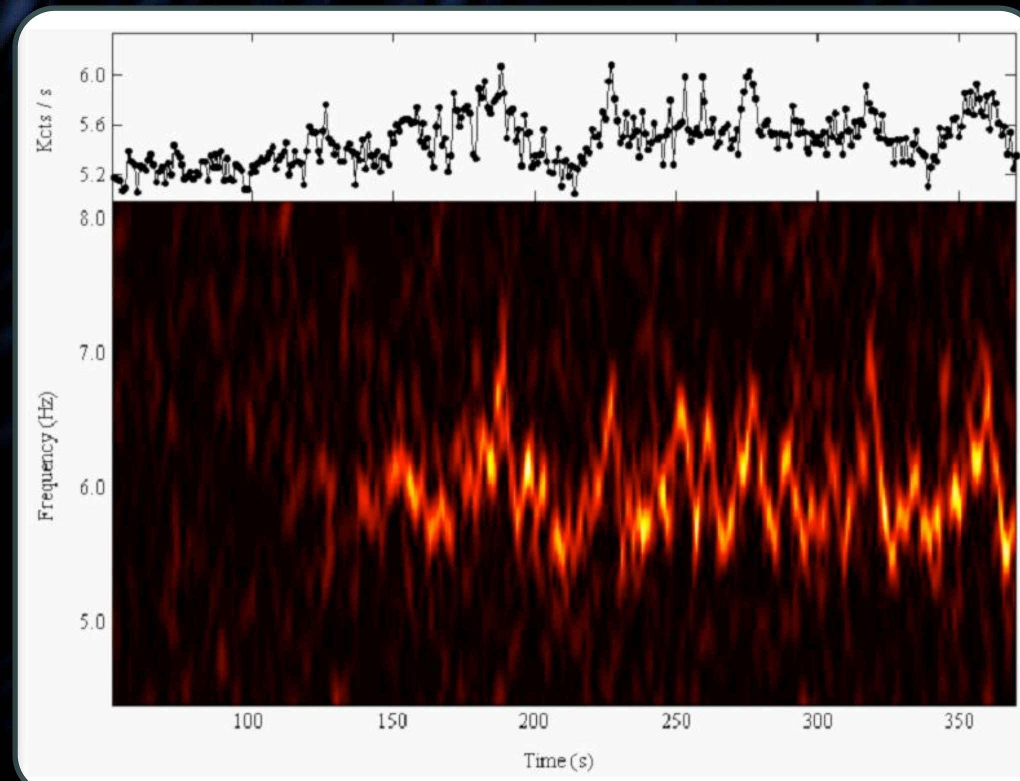
Casella et al. (2004)

Very fast transitions

Timing properties



Casella et al. (2004)

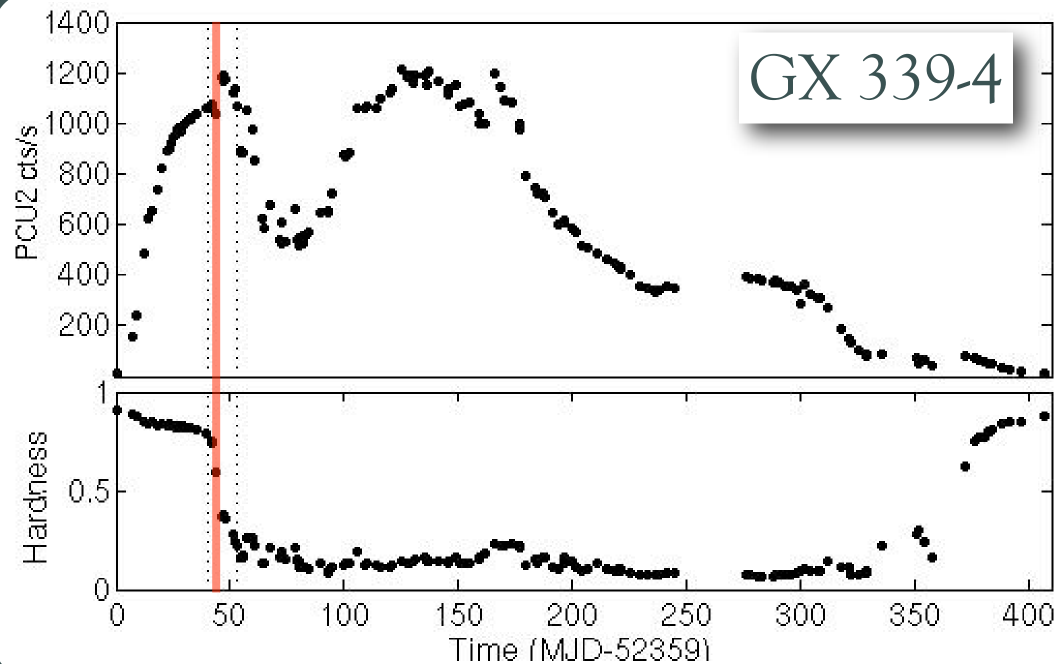


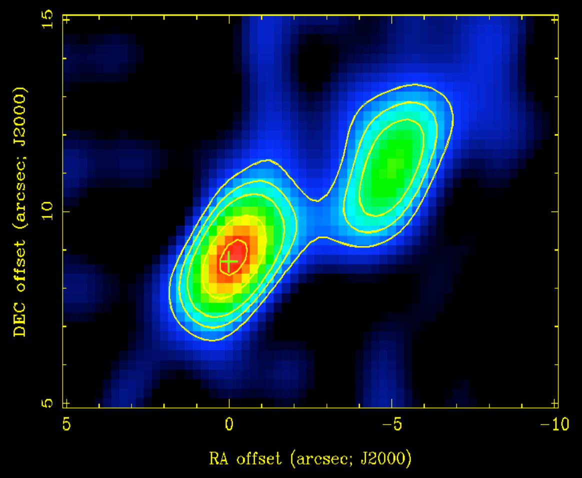
Nespoli et al. (2003)

Powerful ejections

- Related to state transitions
- What happens in between those states?
- Black-hole transients are the key

Belloni et al. (2005)

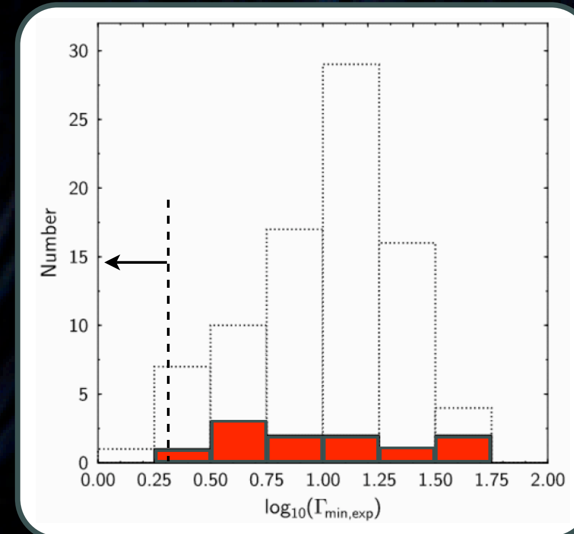




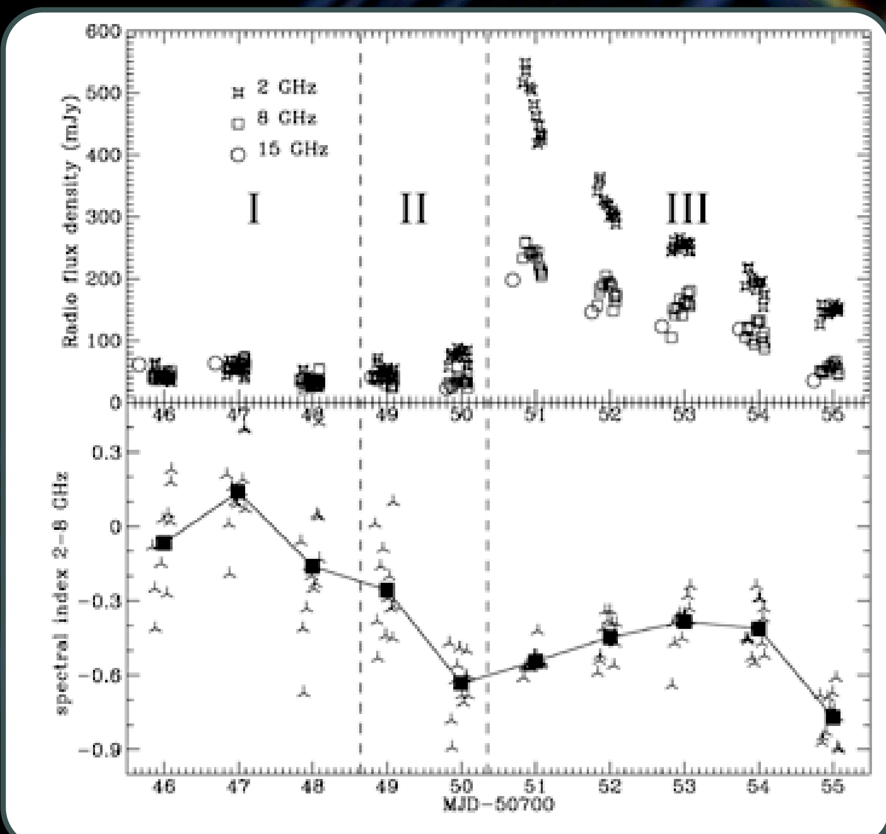
Gallo et al. (2004)

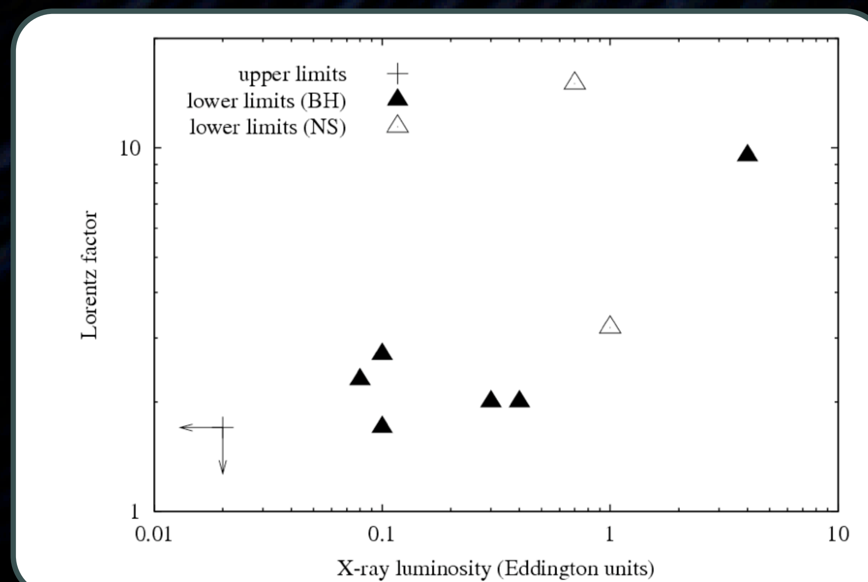
Powerful ejections

- A faster jet
- A different spectrum



Miller-Jones et al. (2006)

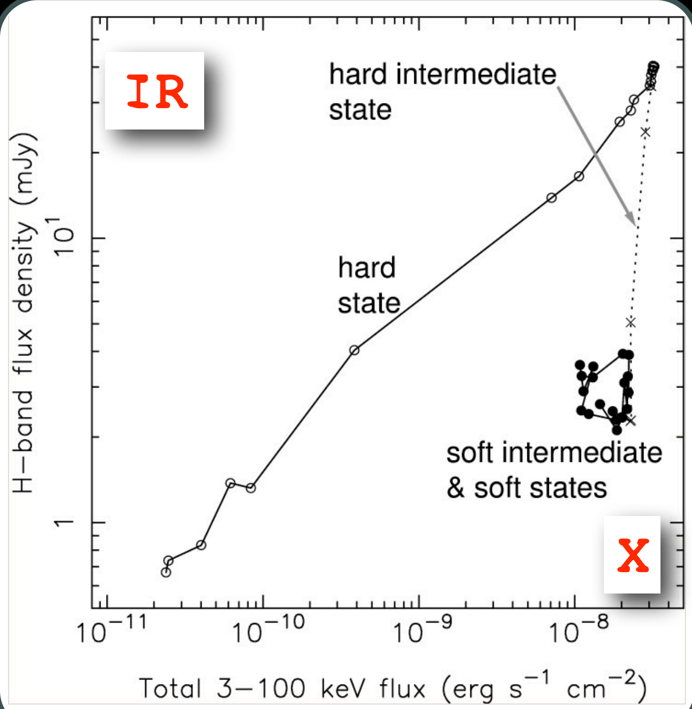




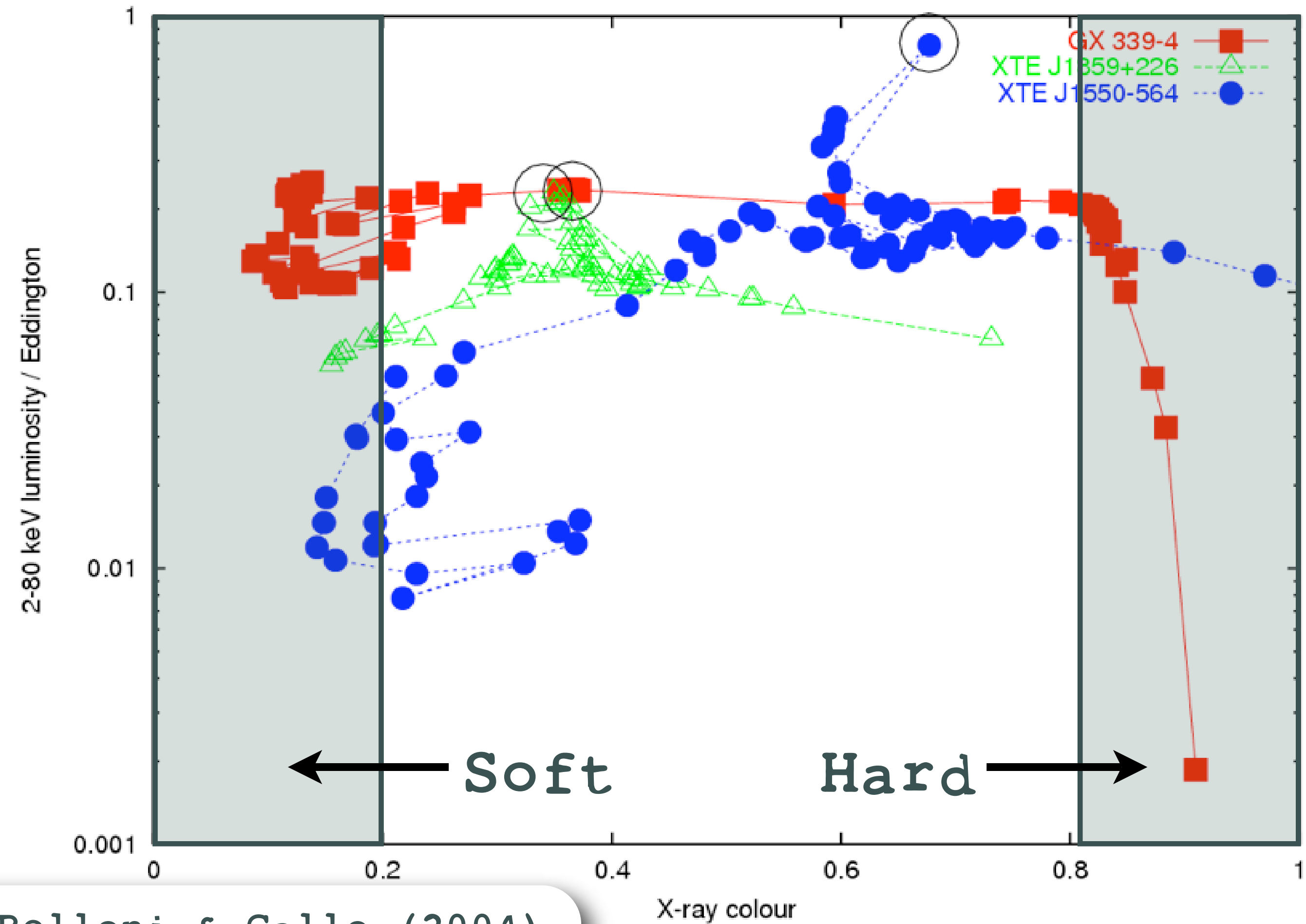
Fender, Belloni & Gallo (2004)

State transitions

- Intermediate states & jet ejections



Homan et al. (2005)



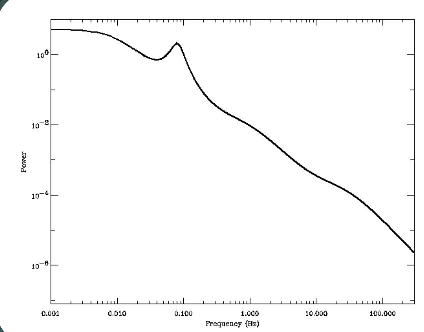
Fender, Belloni & Gallo (2004)

State transitions

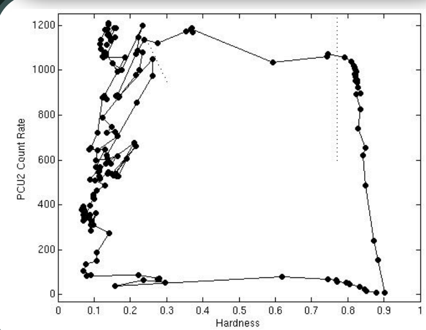
- GX 339-4 as template

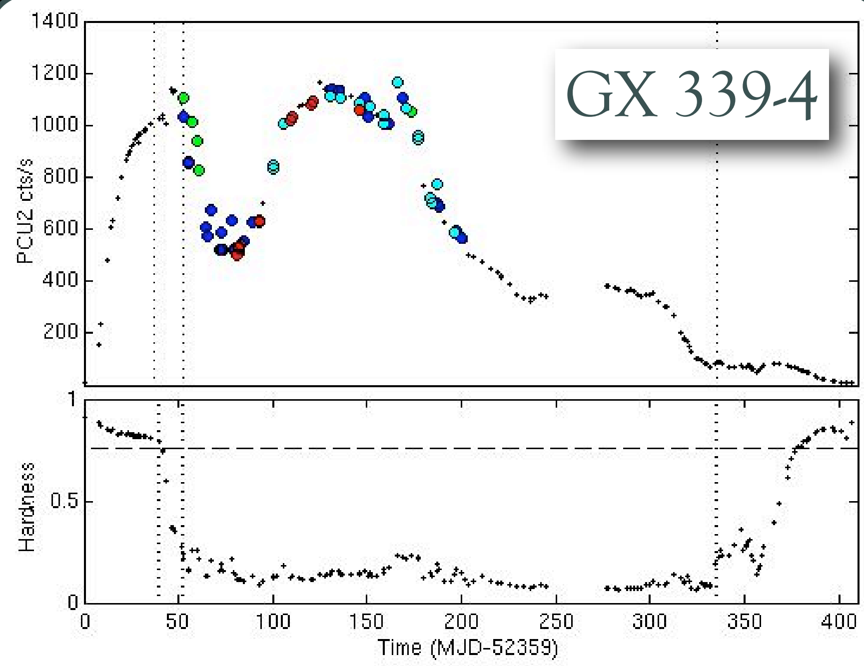
Tools:

Power spectra



Hardness

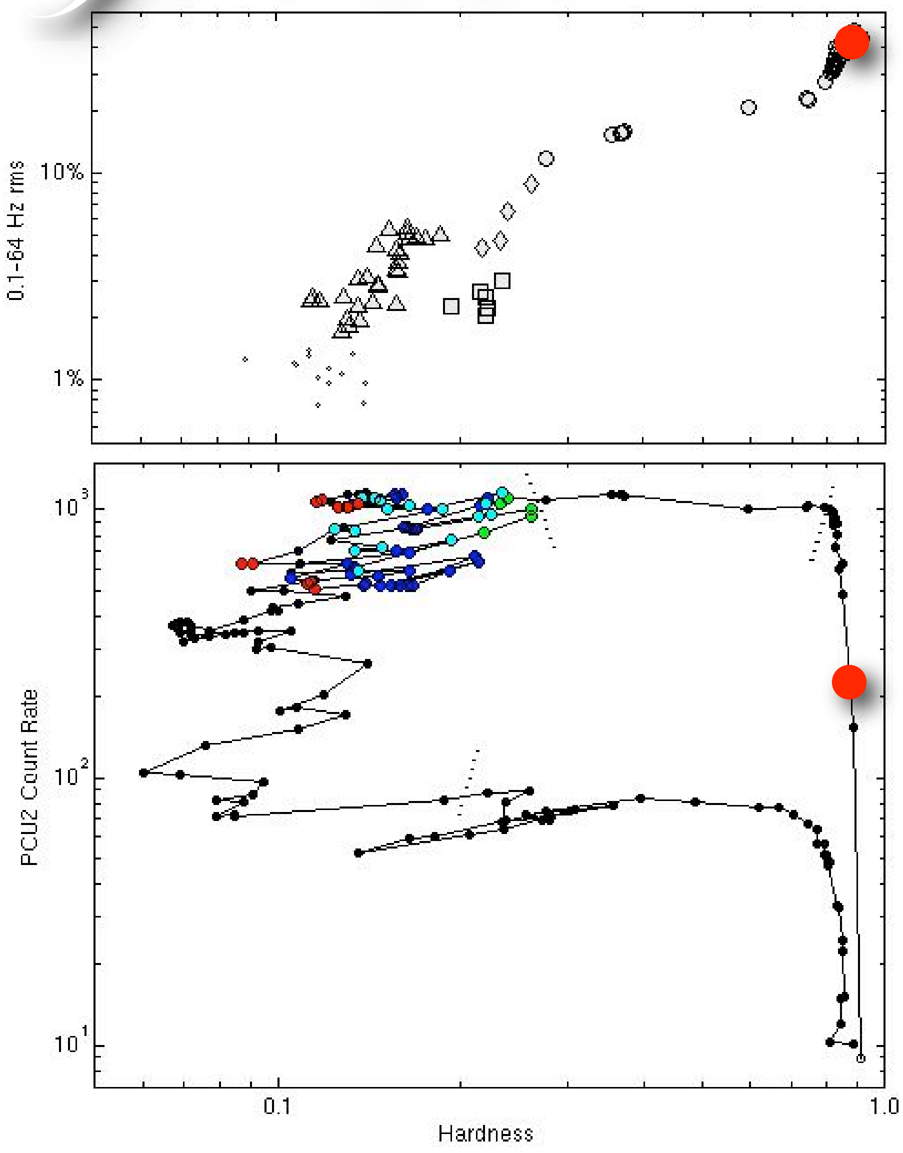




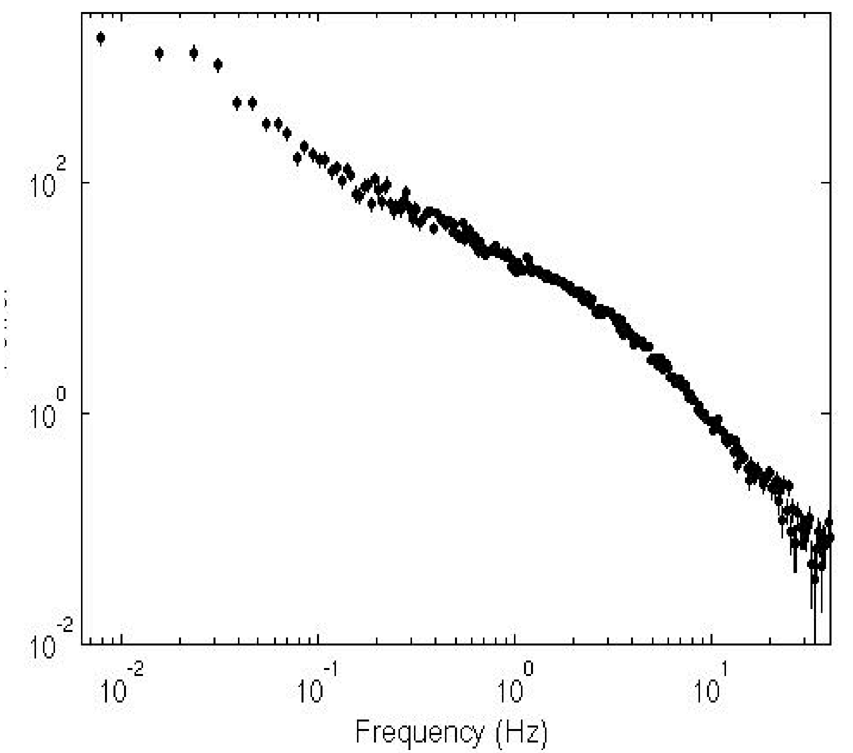
Belloni et al. (2005)

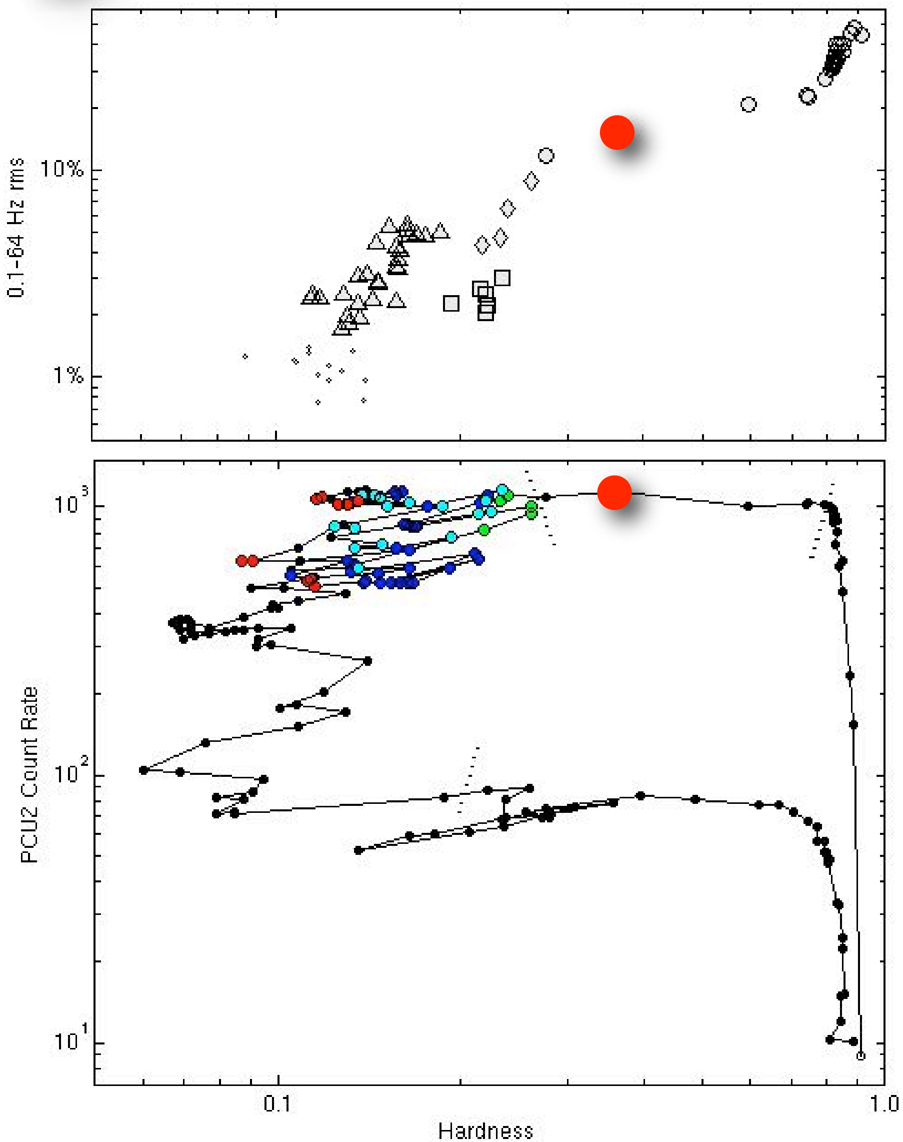
Phenomenology common to many systems

GX 339-4 (2002/3)

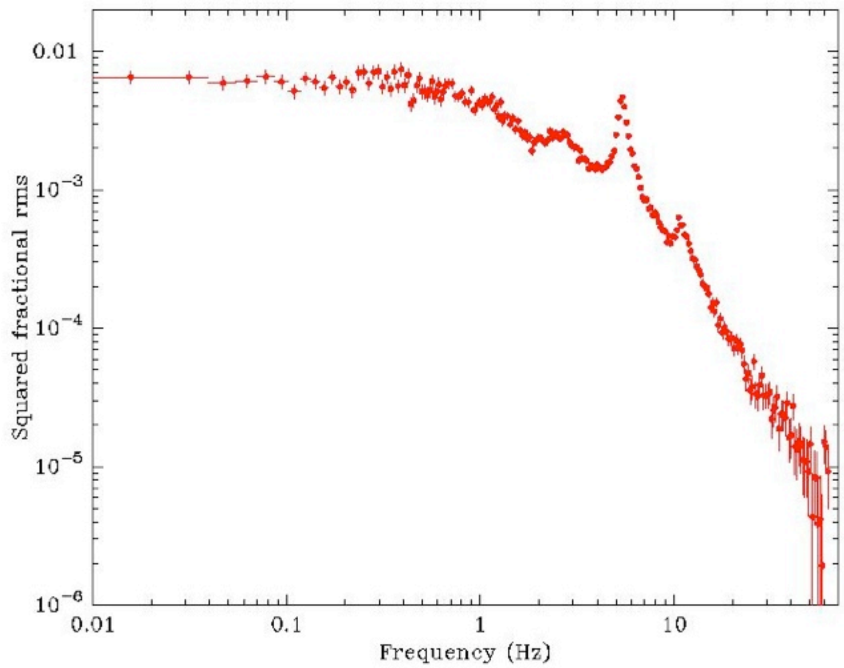


Hard state: noise, high-E cutoff, radio emission, compact jet

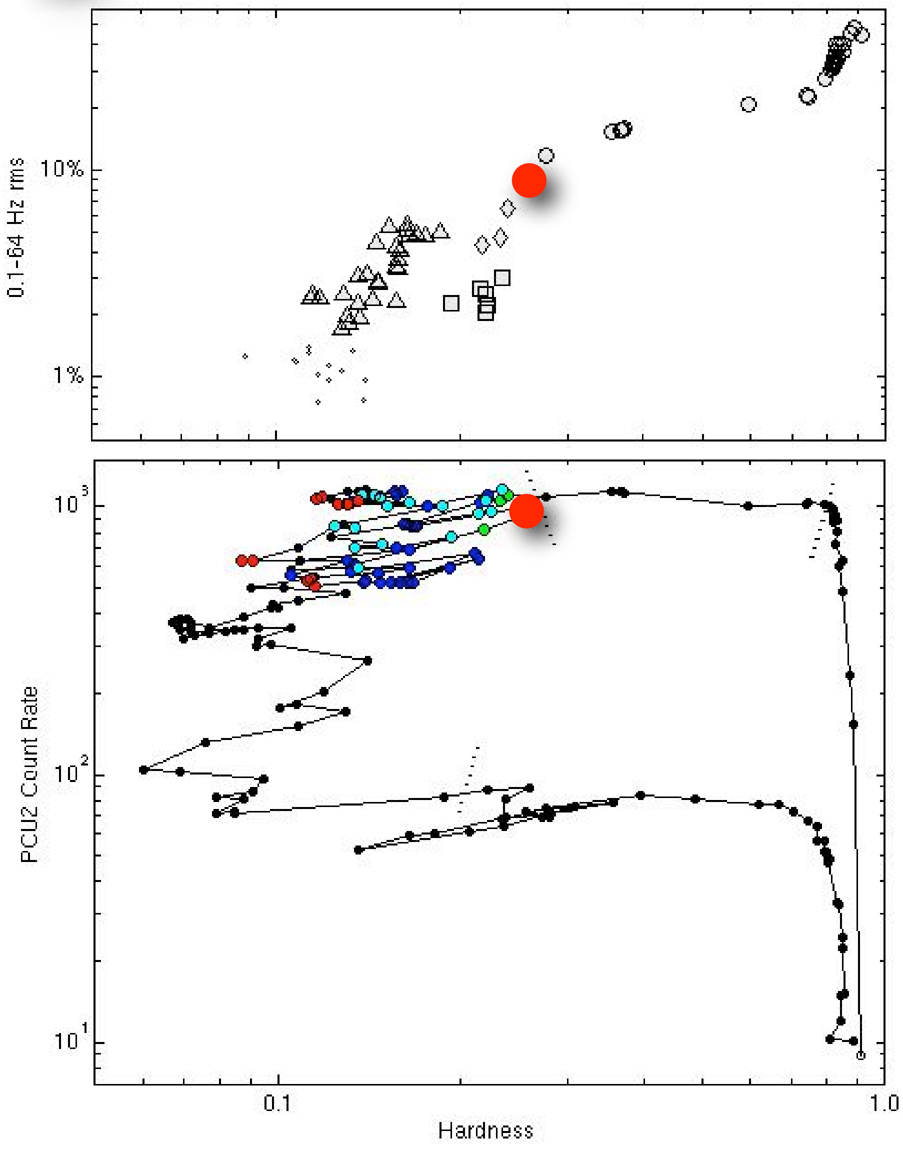


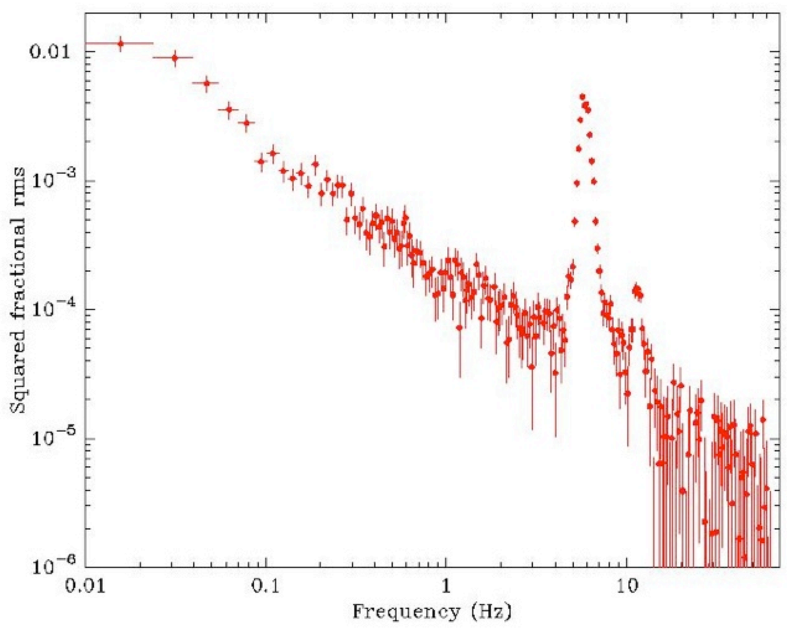


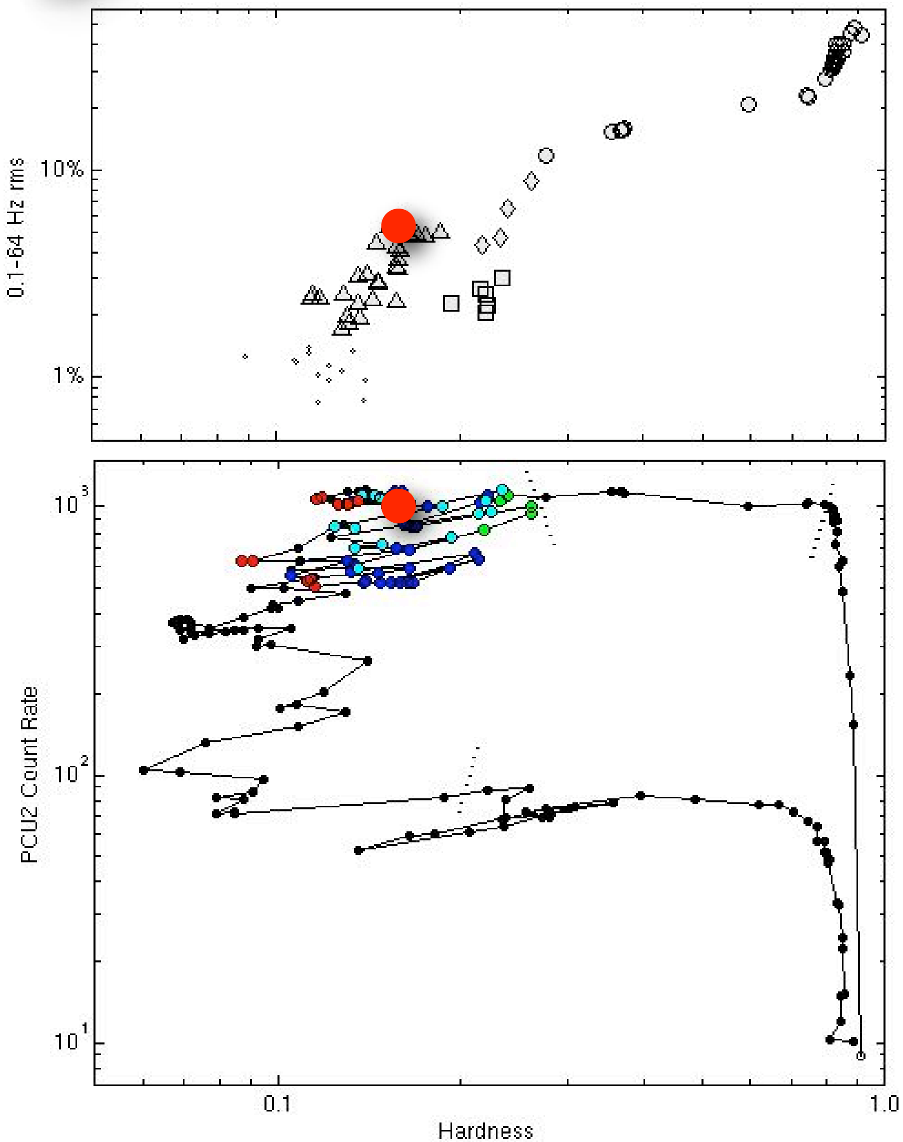
Hard intermediate state: less noise, QPO, high-E cutoff?, radio emission, compact jet



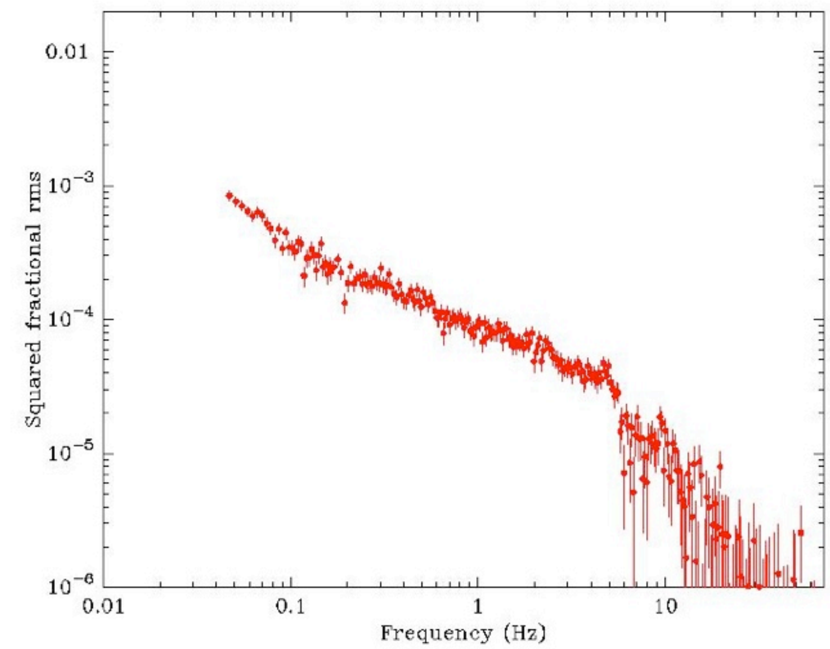
Soft intermediate state: drop in noise, QPO!, high-E cutoff?, no radio emission, jet ejection



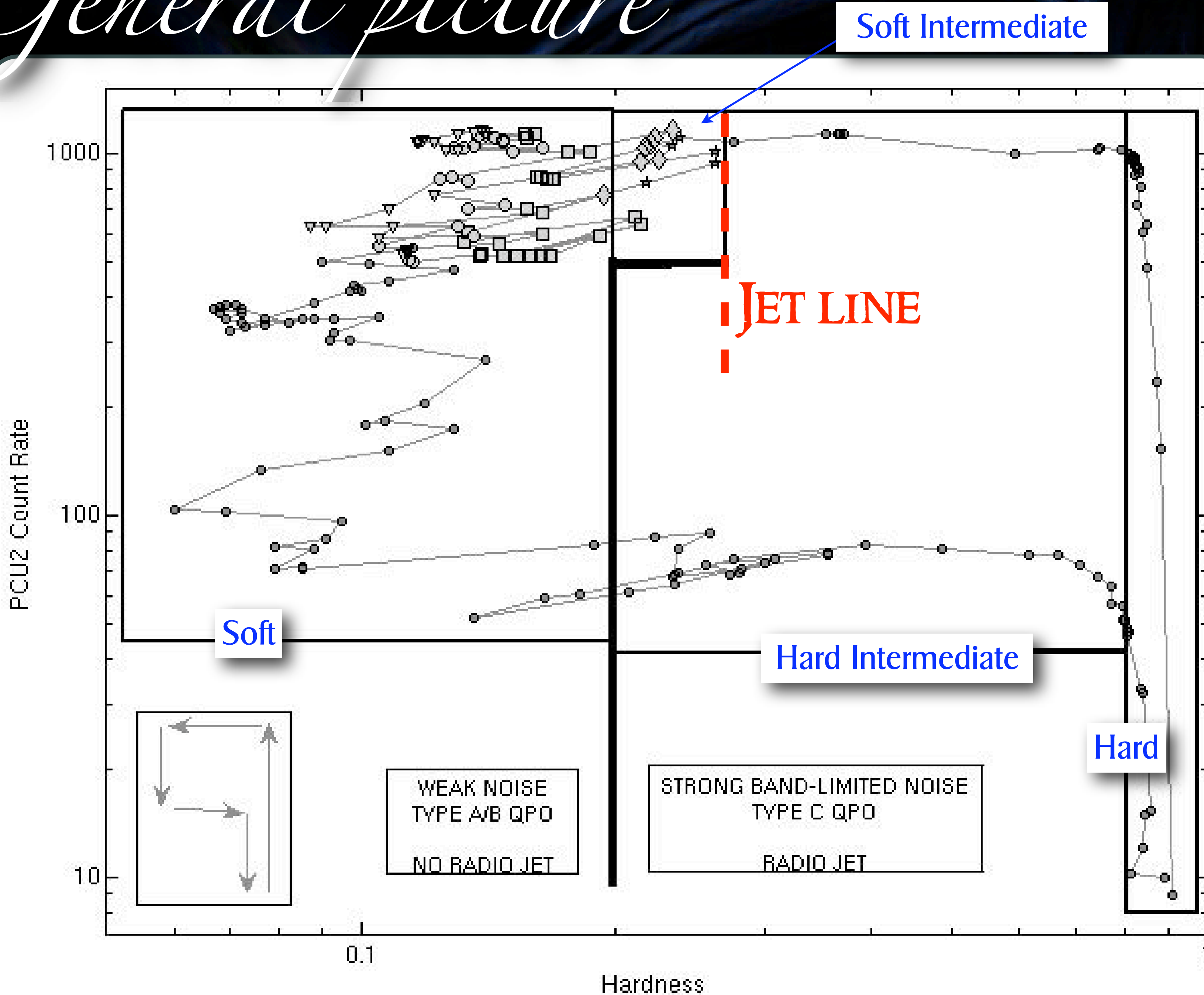




Soft state: little noise, weak QPO, no high-E cutoff, no radio emission



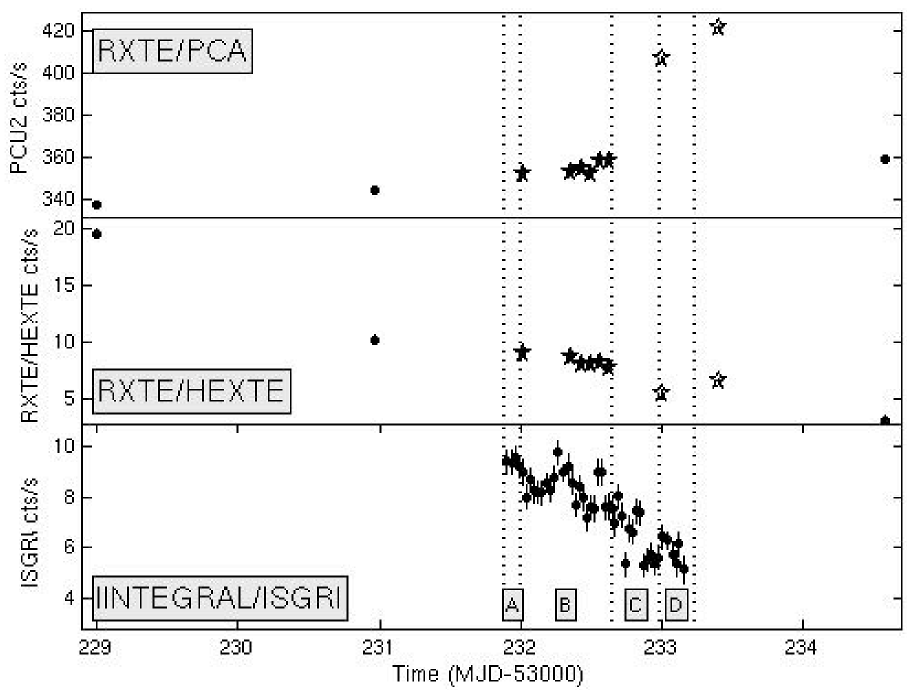
General picture

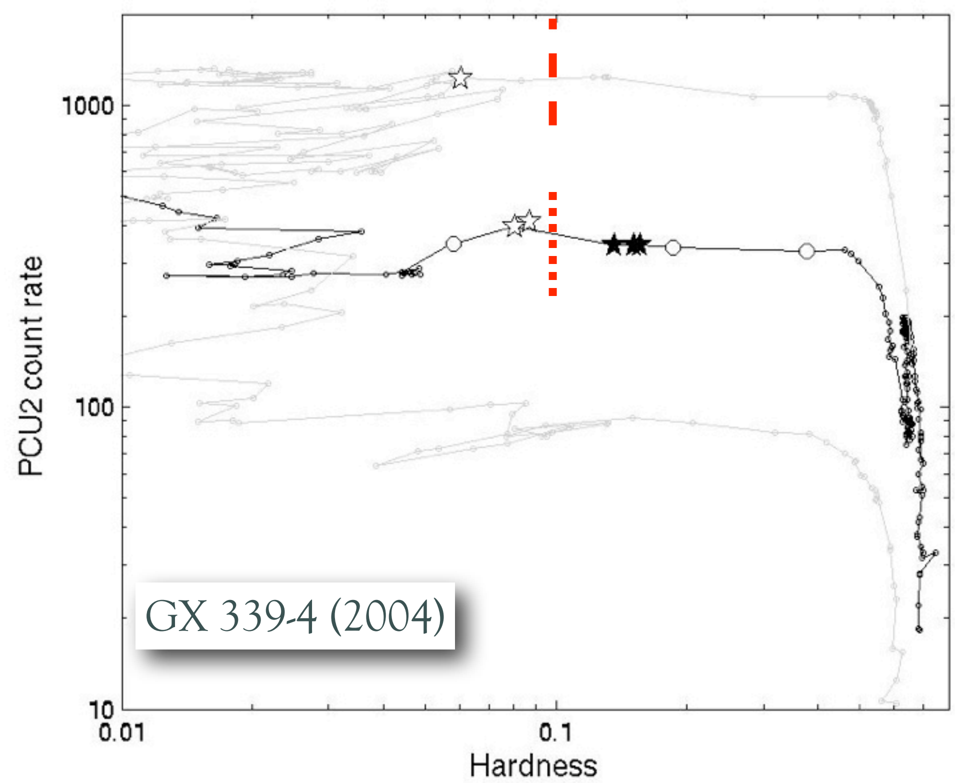


adapted from Belloni (2005)

The Jet Line

- Transitions are fast
- Timing is the tracer
- Jet is the output
- High-energy changes
- Not Mdot driven

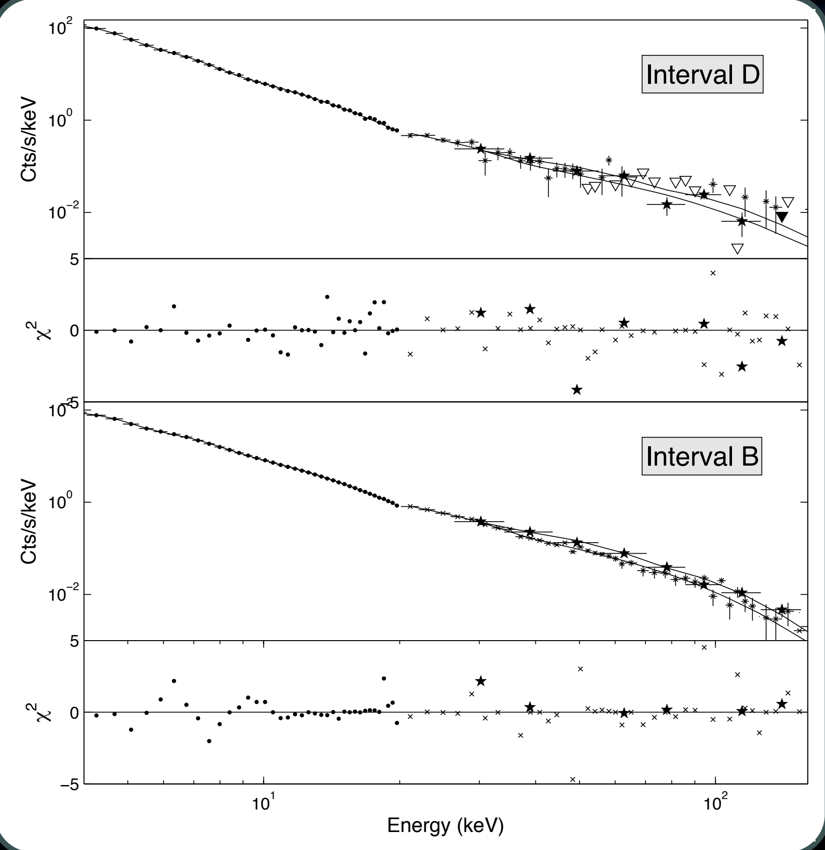


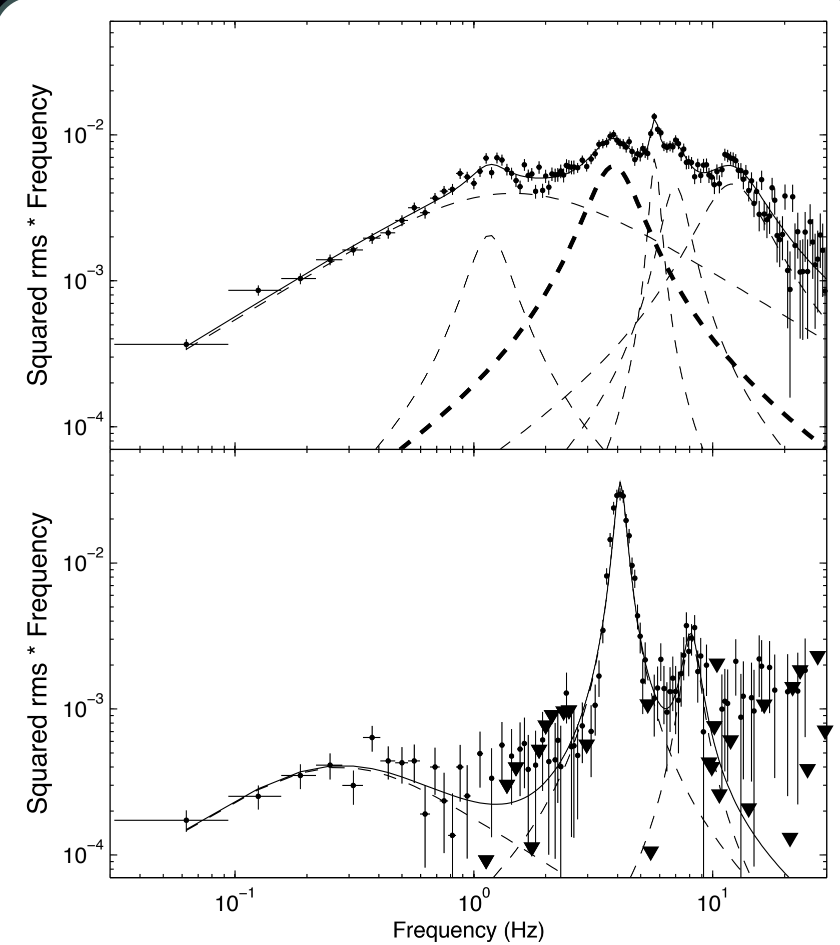


Belloni et al. (2006)

The High-Energy View

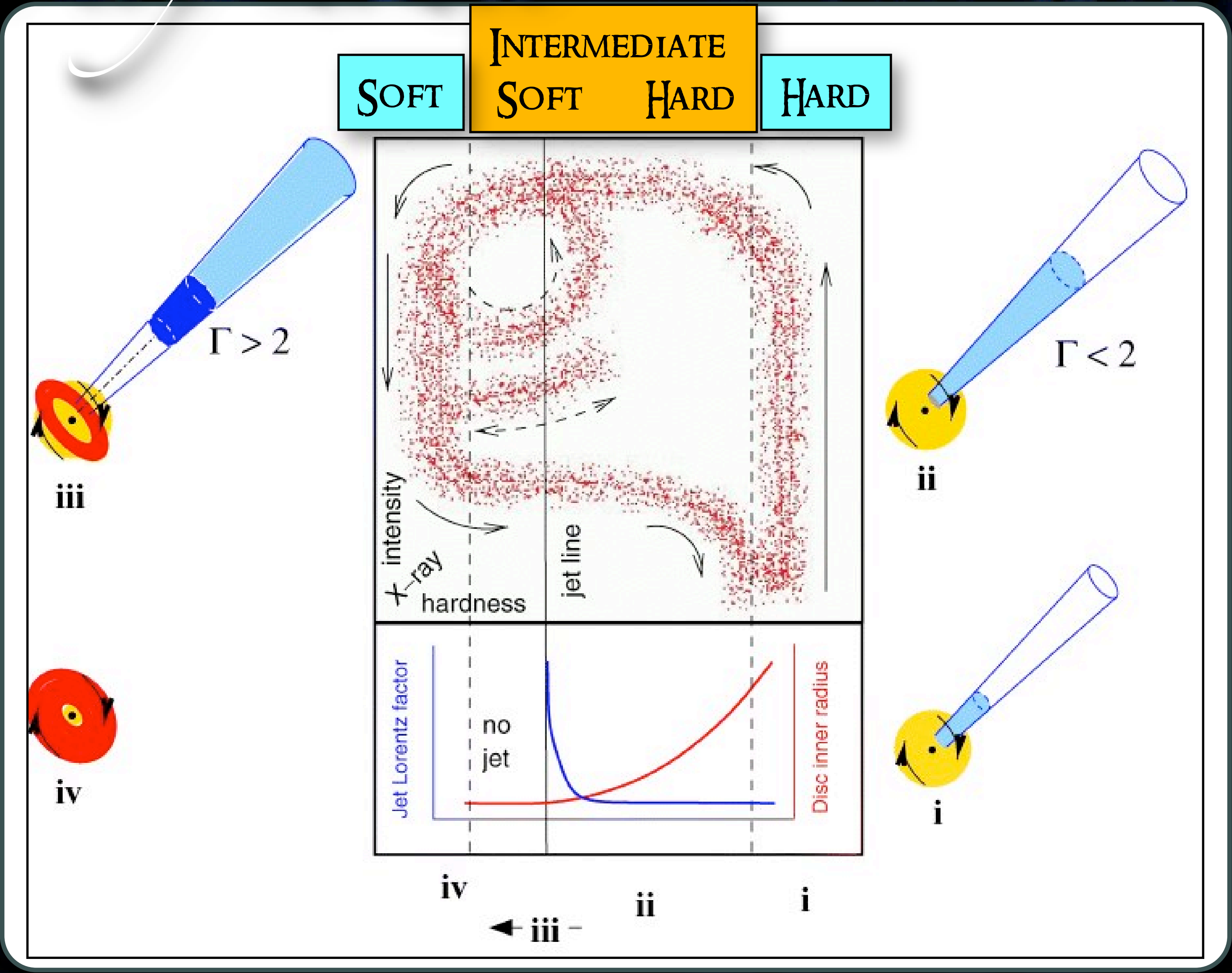
Belloni et al. (2006)





70 keV cutoff disappears

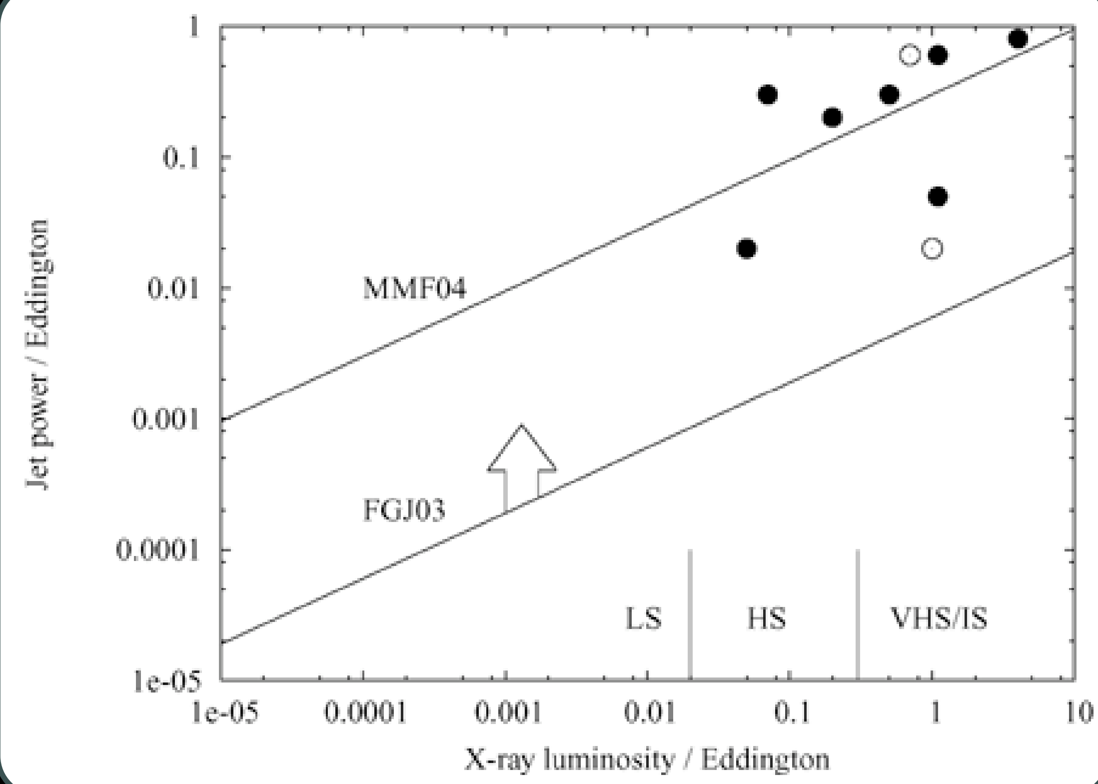
The toy model

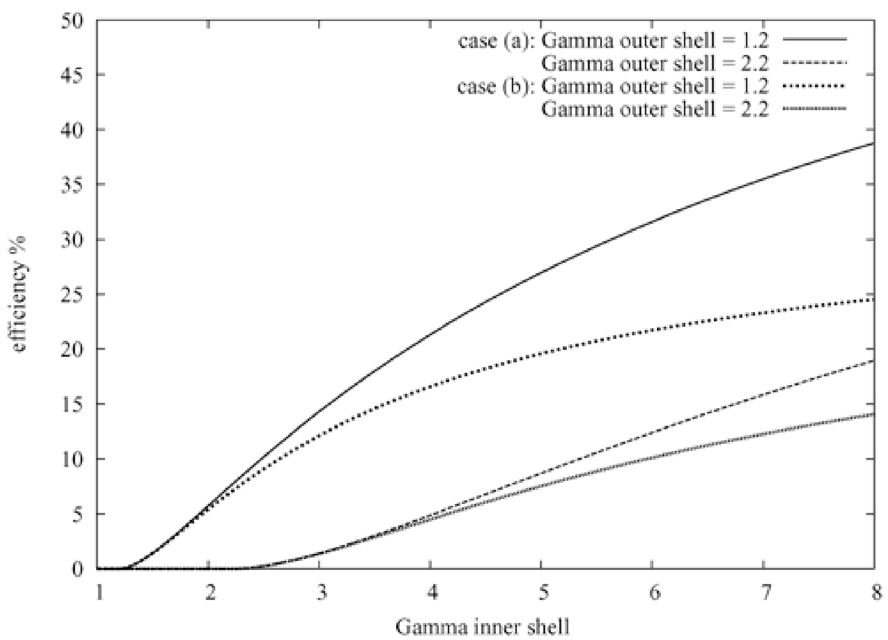


Fender, Belloni & Gallo (2004)

The toy model

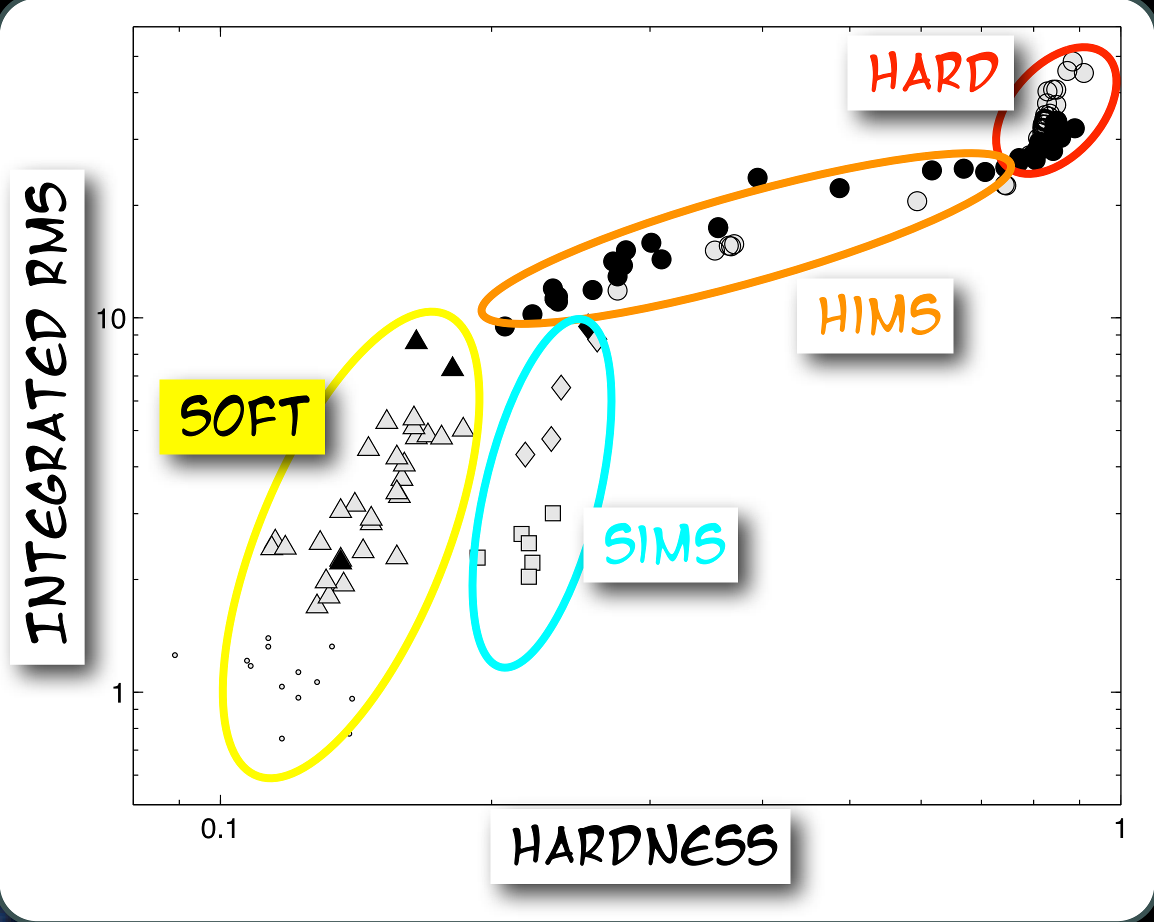
- Continuous evolution of power?
- Internal shocks

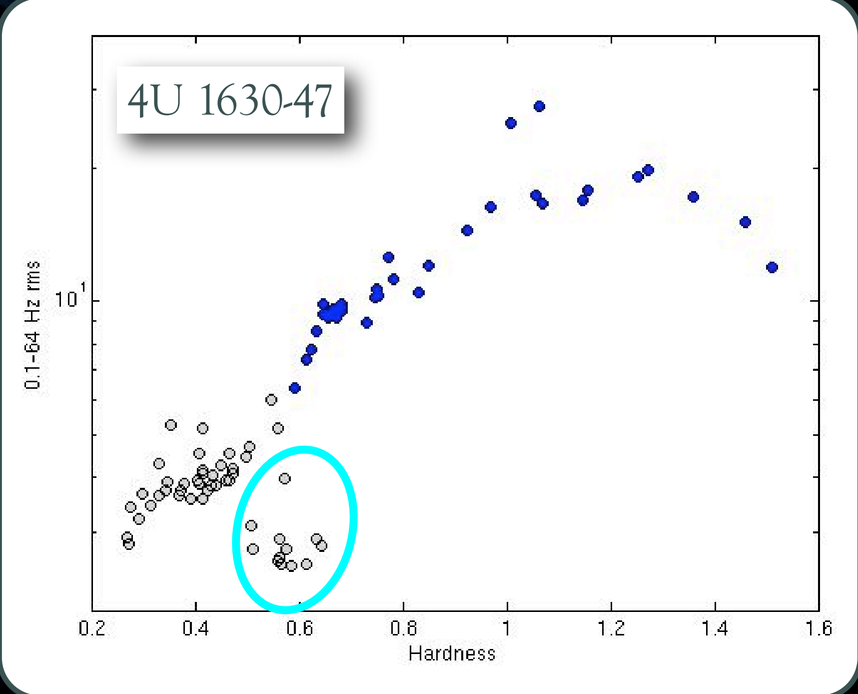




Fender, Belloni & Gallo (2004)

The SIMS region

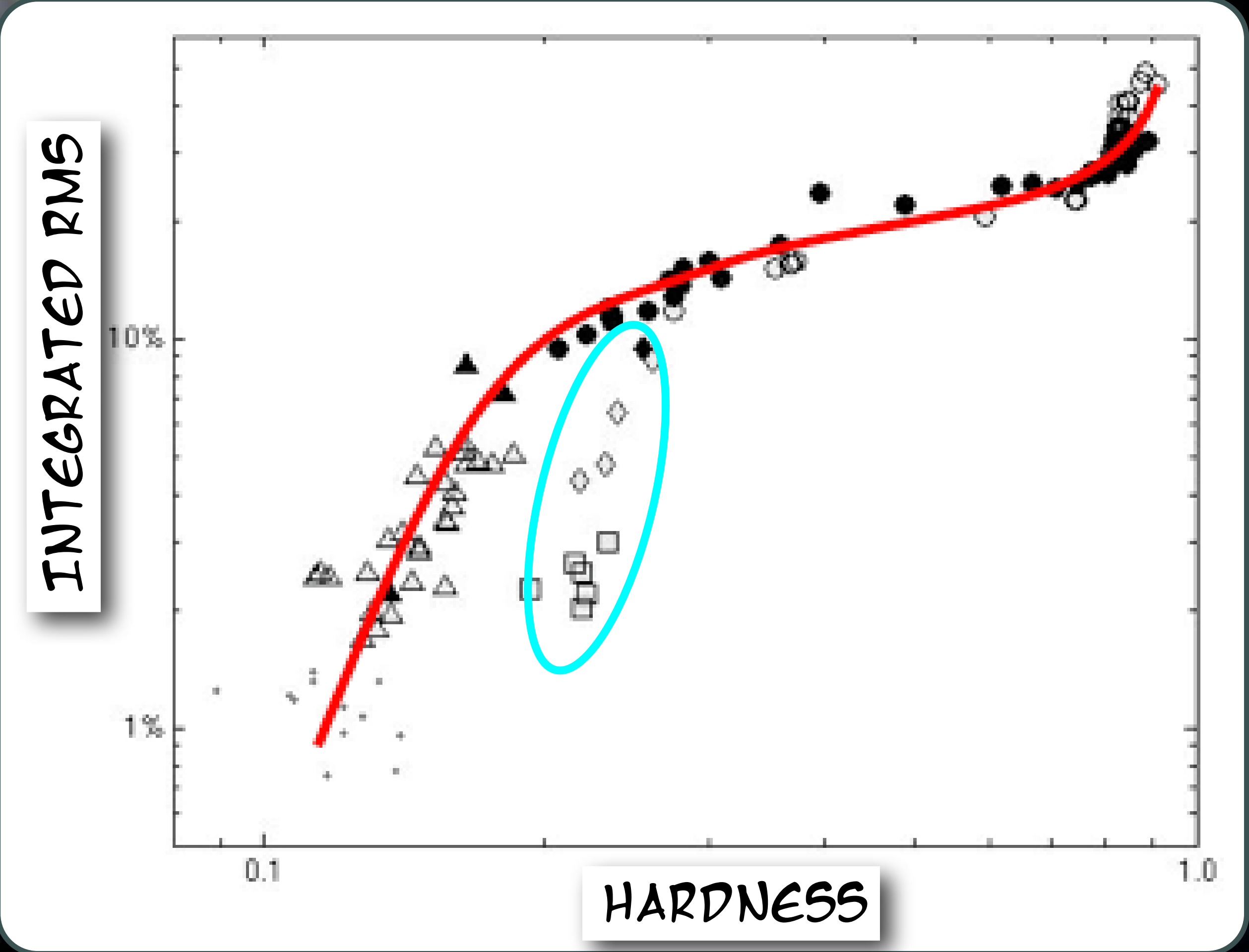




- Different ringing QPO
- Noise drops
- High-frequency QPO
- Not on reverse trans.?

The non-SIMS regions

- Timing properties are continuous from hard to soft
- Sharp transitions only involve the SIMS region
- Energy spectra?



- Clear accretion-ejection connection
- Timing/spectral transitions
- Phenomenology now clearer
- Timing as a tracer of the physics
- Need good multi-band dense coverage
- Comparison with AGN (coming..)

X-ray b

Tom

(Osservatorio Astronomico di Brera)

Thierry Lombry